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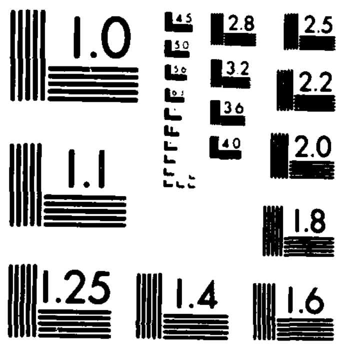

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ANTHROPOMETRIC-ARM RADIOGRAMMETRIC ASSESSMENT OF BODY COMPOSITION, MUSCULARITY AND FRAME SIZE

Annual Report

Frank I. Katch
Albert R. Behnke

June 1, 1983

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The purpose was twofold: (1) to determine the validity of arm radiography to predict total body fat in individuals who differed in relative fitness status (maxVO_2), and (2) to develop k constants that considered fitness, age, and gender. Two hundred subjects (58 young men, 42 older men, 60 young women, 40 older women) were measured for body fat by densitometry. A right upper arm x-ray was taken at KV 76, 1/30th s, 300 MA, and focal length 72 in. Fat width on the x-ray was measured and summed at three sites (FAT,x-ray). The equation to convert FAT,x-ray to individual estimates of percent fat is FAT,x-ray/3F x k constant, where 3F = 3 x $\sqrt{Wt,kg/ht,dm}$, and k is calculated from the equation using the mean values for each age and gender subgroup. MaxVO_2 was measured by a continuous treadmill protocol. The intercorrelations between body fat (density) and FAT,x-ray were r = .884 for the total sample, r = .795 for young males, r = .864 for older males, r = .825 for young females, and r = .828 for older females. Fitness specific k constants were developed for young and older males and females who were classified into high and low fitness categories. The results demonstrate that the arm x-ray technique is valid for estimating percent body fat in young and older men and women who differ in fitness status determined by max$\dot{V}O_2$. The k constants appear to be age, gender, and fitness specific.

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SUMMARY

Two hundred subjects (58 young men, 42 older men, 60 young women, 40 older women) were measured for body fat by densitometry. A right upper arm x-ray was taken at KV 76, 1/30th s, 300 MA, and focal length 72 in. Fat width on the x-ray was measured and summed at three sites (FAT,x-ray). The equation to convert FAT,x-ray to individual estimates of percent fat is FAT,x-ray/3F x k constant, where $3F = 3 \times \sqrt{Wt,kg/ht,dm}$, and k is calculated from the equation using the mean values for each age and gender subgroup. Max$\dot{V}O_2$ was measured by a continuous treadmill protocol. The intercorrelations between body fat (density) and FAT,x-ray were $r = .884$ for the total sample, $r = .795$ for young males, $r = .864$ for older males, $r = .825$ for young females, and $r = .828$ for older females. Fitness specific k constants were developed for young and older males and females who were classified into high and low fitness categories. The results demonstrate that the arm x-ray technique is valid for estimating percent body fat in young and older men and women who differ in fitness status determined by max$\dot{V}O_2$. The k constants appear to be age, gender, and fitness specific.

FOREWORD

Citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

For the protection of human subjects the investigator(s) have adhered to policies of applicable Federal Law 45CFR46.

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Overview

The Phase II research involves the validation of the arm x-ray procedure for quantifying total body fat in samples of young and older men and women grouped by fitness category. Tests were completed on 200 subjects 53 young men, 34 older men, 57 young women, and 36 older women. Body fat was determined densitometrically, fatfolds and girths were taken by standard anthropometric techniques, an x-ray was taken of the right upper arm according to procedures outlined in the Phase 1 report ( ), and fitness was assessed by a treadmill test for maximal oxygen consumption (max$\dot{V}O_2$). Subjects were placed into high and low fitness categories based on relative max$\dot{V}O_2$ ($ml/kg{\cdot}min^{-1}$). The validity correlations were high between body fat determined from the x-ray and body fat determined from body density in subjects grouped by relative fitness category. New k constants were developed specific to age and fitness. The results extend the usefulness of the arm x-ray procedure for quantifying total body fat in males and females of different ages and relative fitness category. The results are limited to Caucasian subjects; the k constants would not be applicable to subjects who exhibit <u>changes</u> in body composition due to exercise or weight loss.

Background Information

The following is a summary of the basic equation used in the present study, and the derivation of the k constant for the conversion of fat thickness from the x-ray to total body fat percentage.

1. **Basic equation.** Percent fat = fat thickness/3F x k, where fat thickness is the sum of six fat widths determined from the x-ray of the upper arm, 3F is a module of body size where F = square root of weight, kg divided by height, dm ($\sqrt{wt/ht}$), and k is a derived constant.

2. **Derivation of the k constant.** Rearrangement of the basic equation permits calculation of the k constant: k = fat thickness/3F x percent fat, where the mean values for percent body fat and 3F are based on a criterion method for percent body fat determined on an independent sample of subjects.

The original k constant developed by Behnke was 0.0471; it was based on a sample of 50 adult men, ages 21 to 67, who represented a variety of body types. Stature ranged from 166 to 207 cm (X = 179.1 cm), and body weight ranged from 58 to 138 kg (X = 84.9 kg). Body fat was estimated in one of two ways; (1) from a regression equation that used body weight and abdominal girth (11), and (2) from height and four trunk and four extremity anthropometric diameters (2). Of the 50 subjects, body density determinations by hydrostatic weighing were made on only four subjects. The correspondence was very close between body fat based on densitometry and the arm x-ray procedures (X = 18.9% body fat from densitometry, and X = 19.7% body fat from the x-ray). Preliminary data were also available on three females; percent body fat was 33.7% calculated from anthropometric diameters, and 39.2% from the arm x-ray. No data were available on the reliability of the x-ray procedures, and the technique was tedious because of the labor intensive nature of measuring the fat widths on the x-ray.

Summary of Results from the Phase 1 Experiment

1. **Derivation of the k constants.** Table 1 summarizes the basic anthropometric data that were used to calculate age and gender specific k constants for the four groups of 25 subjects and the total sample of 100 subjects. For each subject, percent body fat was computed from body density determined by hydrostatic weighing with correction for residual air volume, and from x-ray data computed from the basic equation, % fat = sum 6 fat widths from the x-ray/3F x age and gender specific k constant. The bottom row shows the original Behnke data that was used to compute the original k = .0471. Note the striking similarity between the original Behnke k constant (.0471) and the derived k constant for the new group of 25 older men (.04723).

2. **Influence of new k constants on the calculation of percent body fat.** Table 2 compares percent body fat computed with the newly derived k constants and the original Behnke k constant of 0.0471. Except for the older men, the use of the new k constants yielded significantly lower values for percent body fat than when body fat was computed with the original Behnke k. This was not unexpected because of obvious gender differences in age and body composition.

TABLE 1. Derivation of the age and gender specific k conversion constants for the young and older men and women

Group	N	Height cm	Weight cm	3F[a]	% FAT[b] density	FAT,rads[c] mm	k[d]
Young Men	25	178.2	76.25	6.21	12.85	43.251	.05420
Older Men	25	177.0	77.25	6.27	19.81	58.653	.04723
Young Women	25	165.3	57.60	5.60	21.94	67.036	.05456
Older Women	25	165.2	58.93	5.67	25.10	74.214	.05218
Behnke Data[e]	50	179.1	84.90	6.53	18.70	57.60	.0471

[a] $3F = 3 \times \sqrt{wt/ht}$, where wt, kg; ht, dm

[b] % Fat, density = 495/density - 450 x l00 (Siri conversion of body density from underwater weighing to % body fat)

[c] FAT, rads = sum of fat widths from the x-ray at sites A, B, C

[d] k = FAT, rads (mm)/3F x % Fat, density

[e] Behnke data from 30 compressed air tunnel workers, mean age = 32 years, mean weight = 84.9 kg, where % fat was calculated from LBW based on 8 anthropometric diameters; LBW (sum 8 diameters/33.5)^2 x ht, dm (17.91) x 0.111

TABLE 2. Comparison of Behnke general k constant versus age and gender specific k constants to compute percent body fat from FAT radiographic widths

	PERCENT BODY FAT			
Variable	Young Men (N=25)	Older Men (N=25)	Young Women (N=25)	Older Women (N=25)
Weight, kg	76.25	77.25	57.60	58.93
Height, cm	178.2	177.0	165.3	165.2
3F	6.21	6.27	5.60	5.67
Sum fat widths, mm	43.26	58.66	67.04	74.22
Behnke k value	.0471	.0471	.0471	.0471
Age-gender k value[a]	.0542	.04723	.05456	.05218
Behnke k	14.79	19.86	25.42	27.81
Age-gender k[b]	12.85	19.81	21.94	25.10
Density, underwater weighing	12.85	19.81	21.94	25.10

[a]k = sum fat widths, cm/3F x % Fat, density

[b]% Fat = sum fat widths/3F x k, age-gender specific

3. Estimation of percent body fat from densitometry and the basic and four secondary equations to estimate percent body fat. Table 3 summarizes the intercorrelations between percent body fat determined by densitometry and percent body fat based on radiographic analysis of the x-ray widths. The third column lists the validity correlations between the basic equation and body fat based on densitometry. The other columns display the validity correlations between four secondary equations to compute body fat and body fat determined by densitometry. All of the intercorrelations were highly significant ($p < .01$), and there were no significant differences between the correlations in terms of their magnitude, independent of gender. A unique finding was that substitution of the muscle plus bone widths (B + M) from the x-ray for the six fat widths yielded similar results for percent body fat in the two subgroups of men and women. Table 4 shows the means and standard deviations for percent body fat based on densitometry and the four methods of computing percent body fat from the radiographic analysis of x-ray widths in the young and older males and females and for the total sample. Table 5 presents the means and standard deviations for the x-ray fat widths and percent body fat based on densitometry, and the correlation between the two methods. The validity correlations were highest for the males ($r = .89$ to .90). They were lowest for the young women ($r = .852$) and older women ($r = .864$). The standard errors of prediction were low for percent body fat computed with the basic equation; they ranged from ± 1.84 to ± 2.61 percent fat units among the four subgroups; for the total sample, the error of prediction was ± 2.54 percent fat units. The low standard errors, coupled with the high validity correlations, demonstrated that the arm x-ray procedure was a valid method for estimating body fat content of young and older males and females.

4. Reliability and errors of measurement for the x-ray widths. Table 6 shows the reliability coefficients, t-ratios, and errors of measurement for the various x-ray widths. The top half of the table shows the test-retest reliability coefficients for the muscle plus bone widths at the three x-ray sites for 20 subjects. Reliability at site B was $r = .92$ and $r = .99$ for measurement at sites A, C, and the Total. There were no significant differences in the widths at the three sites when measured on different days ($p > .05$), although the differences between measures were significant (ANOVA, $p < .05$; Scheffe post-hoc comparison, all three widths at sites A, B, and C were significantly different from one another). The average standard

TABLE 3. Intercorrelations between percent body fat calculated from density and percent body fat based on four secondary methods to compute percent body fat based on radiographic analysis of x-ray widths

		Correlations[a]			
Group	N	FAT_{Db} vs SA_{FAT}[b]	FAT_{Db} vs D_{FAT}[c]	FAT_{Db} vs $3F_{FAT}$[d]	FAT_{Db} vs BM_{FAT}[e]
Young Men	25	.889	.858	.891	.897
Older Men	25	.859	.896	.867	.836
Young Women	25	.847	.854	.850	.865
Older Women	25	.868	.866	.870	.867
Total Sample	100	.890	.892	.893	.891

[a]A correlation of $r = .487$ is significant at $P < .01$ for $N = 25$ and $r = .254$ for $N = 100$

[b]SA_{FAT} = (((wt, kg$^{.425}$ x ht, cm$^{.725}$ x 71.84/1000) x FAT, rads x .135)/wt, kg x 100

[c]D_{FAT} = FAT, rads/(sum 11 girths/100) x .0471

[d]$3F_{FAT}$ = FAT, rads/3 $\sqrt{}$wt, kg/ht, dm x .0471

[e]BM_{FAT} = 94 x FAT, rads/B + M rad widths

TABLE 4. Descriptive comparison between percent body fat determined by densitometry and percent body fat determined from radiographic analysis of x-ray widths in young and older men and women

		Percent Body Fat									
		Density[a]		SAFAT[b]		DFAT[c]		3FFAT[d]		BMFAT[e]	
Group	N	X	SD	X	SD	X	SD	X	SD	X	SD
Young men	25	12.85	5.09	14.82	5.97	14.92	6.17	14.76	6.00	13.89	6.55
Older men	25	19.81	6.64	19.77	5.09	19.47	5.41	19.73	5.18	20.30	6.57
Young women	25	21.94	5.18	25.50	5.43	25.20	5.46	25.28	5.50	28.16	6.76
Older women	25	25.10	5.85	27.68	8.54	27.16	8.46	27.52	8.67	30.93	10.69
TOTAL sample	100	19.93	7.23	21.94	8.08	21.69	8.02	21.82	8.11	23.32	10.24

[a] % Fat = 495/density - 450 x 100

[b] SAFAT = ((wt, kg $^{.425}$ x ht, cm $^{.725}$ x 71.84/1000) x FAT, rads x .135)/wt, kg x 100

[c] DFAT = FAT, rads/(sum 11 girths/100) x .0471

[d] 3FFAT = FAT, rads/3 wt, kg/ht, dm x .0471

[e] BMFAT = 94 x FAT, rads/B + M rad widths

TABLE 5. Relationship between radiographic x-ray fat widths and percent body fat determined from body density in young and older men and women, and the correlation between methods

Group	N	X-ray fat widths, mm[a]		% body fat[b]		$r_{1,2}$
		X	SD	X	SD	
Young Men	25	43.25	18.41	12.85	5.09	.899
Older Men	25	58.65	18.58	19.81	6.64	.886
Young Women	25	67.04	17.50	21.94	5.18	.852
Older Women	25	74.21	26.97	25.10	5.85	.864
Total Sample	100	60.79	23.47	19.93	7.23	.890

[a]Sum of 6 fat widths at sites A, B, C

[b]% body fat = 495/density - 450 x 100; density determined by hydrostatic weighing

TABLE 6. Reliability and errors of measurement for x-ray widths

Muscle Plus Bone Widths (N=20)

Site (mm)	Test X	Test SD	Retest X	Retest SD	$r_{1,1}$[a]	t[b]	Sem[c]
A	97.74	11.89	97.44	12.18	0.99	1.46 (NS)	1.20
B	77.60	11.09	78.39	10.61	0.92	1.06 (NS)	1.09
C	72.12	10.90	72.28	10.76	0.99	-1.81 (NS)	1.08
Total[d]	247.46	32.01	248.11	32.18	0.99	0.36 (NS)	3.21

Fat, Muscle, Bone, Marrow, Cortex (N=16)

Width (mm)	Day 1 X	Day 1 SD	Day 2 X	Day 2 SD	$r_{1,1}$	t	Sem
Fat	62.97	19.71	62.95	19.68	0.99	0.33 (NS)	1.97
Muscle	171.87	28.19	171.90	28.25	0.99	0.51 (NS)	2.82
Bone	63.07	7.19	63.06	7.09	0.99	0.37 (NS)	0.71
Marrow	33.18	5.72	33.19	5.74	0.99	0.38 (NS)	0.57
Cortex	29.90	3.76	29.86	3.63	0.99	0.47 (NS)	0.37
Total Widths	297.91	37.64	297.90	37.68	0.99	0.20 (NS)	3.77

[a]Test-retest reliability coefficient
[b]A $t = 2.85$ is required for $P < 0.01$ for $N = 20$ and 2.12 for $N = 16$
[c]Standard error of measurement; $SD\sqrt{1-r_{1,1}}$, where SD = average SD from duplicate measures
[d]Sum of x-ray widths at lines A, B, C

error of measurement for the three sites was 1.12 mm, or 1.4% of the mean width for the A, B, and C widths.

The bottom half of Table 6 displays the pertinent comparisons for 16 additional duplicate x-rays that were also remeasured for purposes of determining reliability of measurement. As was the case for the remeasurement of the x-rays on different days, the standard errors of measurement were also very low for the x-ray widths measured on two consecutive days. The standard errors averaged 1.7% of the mean values for the various width components (T-3; p.13, Phase 1).

When duplicate x-rays were taken 10 minutes apart on six subjects, there were no significant differences for any of the width measures for fat, muscle, or bone (marrow and cortex) at lines A, B, and C. The largest difference between any of the duplicate measurements on the two x-rays was 0.96 mm for muscle width at line B (mean difference of 2.0%). For fat width, the mean difference was 0.05 cm at line A (0.4%), 0.70 mm at line B (2.6%), and 0.48 mm at line C (2.6%). The mean difference between the sum of six fat widths on the two sets of x-rays was 0.31 mm (x-ray 1 = 65.88 mm and x-ray 2 = 65.57 mm; less than 0.5%).

5. Comparison of techniques for measuring the x-ray widths. There were two different techniques used to secure the measurements from the x-rays. The first procedure used a metal dial caliper that was read to the nearest 0.05 mm. The second procedure made use of a sonic digitizer interfaced to a minicomputer. The X-Y coordinates on the x-ray film were determined by digitizing the x-ray widths of fat, muscle, and bone at sites A, B, and C. Table 7 compares the dial caliper and digitizer measurements for N = 98.

All of the correlations between the dial caliper and digitizer methods were $r = .99$ or higher, and there were no significant differences between any of the comparisons ($p > .05$). On a percentage basis, the largest mean differences between the two methods occurred for the marrow widths (1.21 to 2.22%); the mean difference was 1.48% for bone at site B, but only 0.08 to 0.61% for measures of total width and muscle + bone widths. For all of the comparisons, the discrepancies were very small and had a trivial influence on subsequent calculations. In terms of time, the digitizer method was preferable because of the time saved in making the

TABLE 7. Comparison of dial caliper and digitizer methods for comparing x-ray widths

	Dial Caliper		Digitizer		
X-ray site, mm	X	SD	X	SD	r
Total width A	121.53	16.462	121.41	16.489	.987
Total width B	109.01	19.586	108.66	19.753	.993
Total width C	95.52	16.508	95.22	16.667	.988
Muscle + Bone A	100.81	14.573	100.98	14.395	.998
Muscle + Bone B	83.16	14.866	83.04	14.788	.999
Muscle + Bone C	78.13	14.982	78.00	15.005	.998
Bone A	23.55	3.067	23.57	3.111	.993
Bone B	23.64	3.057	23.99	4.845	.994
Bone C	19.91	2.306	19.79	2.411	.996
Marrow A	14.43	2.760	14.25	2.664	.999
Marrow B	12.54	2.578	12.39	2.640	.999
Marrow C	9.65	1.589	9.44	1.657	.999

measurements, but the use of either method gave comparable results.

During Phase 1 (6), we observed that the theoretically derived k constants that were used to transform the x-ray data into meaningful estimates of body fat for the individual did not seem to apply to athletes or to individuals who were muscular in physique and relatively thin in appearance. For those people, the estimation of body fat by the x-ray procedures severely underestimated their body fat content compared to densitometry. The conversion constants developed for young and older males and females, as well as the 50 male tunnel workers originally tested by Behnke (B&W), appeared to be valid for relatively untrained persons of normal body composition. If the constants were universal in nature, they would not have over predicted the fat content of the muscular and thinner subjects who appeared to be physically fit (less body fat and a higher muscle mass). The evaluation of individuals ranked high and low in fitness, and then compared for fatness by the arm radiogrammetric method and densitometry, would allow for the development of new k constants based on fitness status, age, and gender.

The major purpose of the present Phase 2 research was to validate the arm radiogrammetric assessment of body fat in individuals who differed in relative fitness status, and to develop appropriate k constants that considered fitness, age, and gender.

Methodology

Subjects. Two hundred subjects were recruited by local advertising; they were faculty, staff, and students at the University of Massachusetts, Amherst. All subjects signed an informed consent document in accordance with University and Federal guidelines for the protection of human subjects (Appendix A). For the statistical analysis, two age categories were created; younger age subjects, 18.0 to 29.9 years, and older age subjects, 30.0 to 39.9 years. There were 58 young men, 42 older men, 60 young women, and 40 older women. Table 8 compares the age, height, weight, body density, absolute and relative fat, lean body weight, residual lung volume, and lean to fat ratio between the young and older males and females.

Anthropometric measurements. The following anthropometric measurements were taken on each subject; the procedures were identical to the measurements taken in the Phase 1

TABLE 8. Comparison of physical characteristics of subjects (Phase II)

Variable	Young Men (N=58)		Older Men (N=42)		Young Women (N=60)		Older Women (N=40)	
	X	SD	X	SD	X	SD	X	SD
Age, years	23.3	4.01	35.0	2.92	22.9	4.39	34.3	2.95
Height, cm	176.9	7.35	177.8	5.77	167.0	5.97	165.1	6.82
Weight, kg	73.0	8.94	75.5	9.46	60.3	8.82	60.5	7.96
Body Density, g/ml[a]	1.072	0.011	1.060	0.013	1.047	0.012	1.043	0.014
Body Fat, %[b]	11.8	4.70	16.9	5.64	22.9	5.65	24.8	6.37
Fat Weight, kg	8.8	3.88	12.9	5.45	14.0	4.64	15.2	5.23
Lean Body Weight, kg	64.3	7.47	62.6	7.10	46.2	6.18	45.1	4.77
Residual Volume, L[c]	1.624	0.360	1.967	0.446	1.398	0.337	1.645	0.321
Lean/Fat Ratio[d]	10.074	7.427	5.731	2.785	3.664	1.265	3.346	1.283

[a]Hydrostatic weighing with correction for residual lung volume

[b]% Fat = 495/density - 450

[c]Average of test-retest; O_2 dilution procedure

[d]Lean body weight, kg/Fat weight, kg

study (6). An exception was the addition of ultrasound measurements that were taken at the same seven sites as the fatfolds.

1. Fatfolds. The measurements were made with a Lange caliper on the right side of the body with the subject standing. Three measurements were taken at each site in rotational order and the average value used as the criterion score. The anatomical locations for the five measured fatfold sites were as follows:

1. Triceps: vertical fold measured at the midline of the uppei arm halfway between the tip of the shoulder and the tip of the elbow.

2. Subscapula: oblique fold measured just below the bottom tip of the scapula.

3. Supra-iliac: oblique fold measured just above the hip bone (the fold is lifted to follow the natural diagonal line at this point).

4. Abdomen: vertical fold measured 1 inch to the right of the umbilicus.

5. Thigh: vertical fold measured at the midline of the thigh, two-thirds of the distance from the mid knee cap to the hip joint.

2. Bone diameters. The right and left sides were measured for the wrists, elbows, knees, and ankles. The measurements were taken with a Siber-Hegner anthropometer as follows:

1. Biacromial: subject seated, elbows in contact with the body, and hands resting on the thighs. The distance was measured between the most lateral projections of the biacromial processes.

2. Bi-iliac: subject stands with arms at sides. The distance was measured between the outermost portions of the iliac crests, taking care to measure as close to the hard bony surfaces as possible.

3. Bitrochanteric: subject stands with arms at sides. The distance was measured between the most lateral projections of the trochanters, taking care to measure as close to the hard bony surfaces as possible.

4. Chest: subject stands with arms at sides. The lateral width of the chest at the level of the fifth and sixth ribs was measured during normal breathing (nipple line in males and upper part of breasts in females).

5. Wrists: subject seated with the hands resting on the thighs. The distance was measured between the styloid processes of the radius and ulna.

6. Elbows: subject seated. The distance was measured between the epicondyles of the humerus with the elbow flexed, forearm supinated, and the hand supported by the examiner.

7. Knees: subject seated with knee flexed to a right angle. The distance was measured between the tibial condyles at the greatest point.

8. Ankles: subject standing on a table. The distance was measured between the malleoli with the anthropometers inclined upward at a 45 degree angle.

3. **Girths.** A cloth measuring tape was used. The tape was applied lightly to the skin surface so that the tape was taut but not tight. Duplicate measurements were taken at each site and the average used as the criterion circumference score. The anatomic landmarks for the various girth measurements were as follows:

1. Shoulders: maximal protrusion of the bideltoid muscles and the prominence of the sternum at the junction of the second rib.

2. Chest: for men about one inch above the nipple line; for women at the axillary level. Note: in men and women, the tape was placed in position with the arms held horizontally. The arms were then lowered and the measurement recorded at the mid-tidal level of respiration.

3. Abdomen: the average was taken of the following two circumferences: (1) the conventional circumference of the waist just below the rib cage at the minimal width, and (2) level of the iliac crests at the navel.

4. Buttocks: maximal protrusion and, anteriorly, the symphysis pubis. The heels were kept together.

5. Thighs: crotch level at the gluteal fold.

6. Biceps: maximal circumference with the arm fully flexed and fist clenched.

7. Forearms: maximal circumference with the arm extended and palm up.

8. Wrists: the circumference distal to the styloid processes of the radius and ulna.

9. Knees: the middle of the patella with the knee relaxed in slight flexion.

10. Calves: maximal circumference.

11. Ankles: minimal circumference just above the malleoli.

4. Ultrasound. The measurements were made with an A-scan ultrasonic device (Body Composition Meter, Ithaco, Inc., Ithaca, New York). The Body Composition Meter (BCM) works on the principle that high frequency sound waves (2.5 mHz) are emitted from the transducer head of the BCM and penetrate the skin surface. The sound waves pass through the adipose layer until the muscle layer is reached, where they are reflected from the fat-muscle interface. This produces an echo that returns to the transmitter that also acts as a receiver. The time it takes from transmission of the sound waves through the tissue and back to the receiver is converted to a distance score and displayed on an LCD readout on the panel meter. The BCM can measure fat to 50 mm thickness (to the nearest one mm) on the lower scale, and to 100 mm thickness (to the nearest 2 mm) on the upper scale.

Seven sites were measured that corresponded to the exact anatomical locations defined for the fatfold subcutaneous measurements (4).

A. Triceps - halfway between acromion and olecranon, in line with the proximal point of the ulna.

B. Biceps - directly in line with the center of the cubital fossa at the same level as the triceps site.

C. Subscapula - 2 cm below the inferior angle of the scapula.

D. Abdomen - 5 cm to the right and at the level of the umbilicus.

E. Iliac - 2 cm medial to the anterior-superior spine.

F. Thigh - anterior thigh midway between the anterior-superior iliac spine and mid-patella.

G. Calf - medial side, one-third the distance from the medial border of the popliteal angle to the inferior point on the medial malleolus.

All measurements are taken on the right side of the body with the subject either standing or lying comfortably on a cot. For measurements made in the prone lying position (triceps and subscapula), the arms were kept at the side of the body. The approximate measurement site was cleaned with isopropyl rubbing alcohol and then the exact site of measurement was marked with a felt tip pen. The open end of a disposable cardboard mouthpiece was then inked from an ordinary ink pad, and an impression made around the center of the felt tip dot on the skin surface. A dab of mineral oil was applied to the skin surface to act as an interface between the transducer head and skin surface.

5. Densitometry and residual lung volume. Body density was determined for each individual by the hydrostatic weighing procedure (3) with correction for residual lung volume (RLV). Ten to twelve trials of underwater weight were recorded, and the average of the last three trials was used as the subject's underwater weight score. Water temperature was maintained at 98-99 degrees Fahrenheit. A scuba diver's belt was worn around the waist by all of the subjects. Prior to underwater weighing, body weight was measured to the nearest ±25 grams on a Homs beam balance scale. Height was measured to the nearest 0.1 cm with a stadiometer. Percent body fat was estimated from body density by the equation of Siri; percent fat = 495/density - 450 (9). Residual lung volume (RLV) was measured by oxygen dilution in the same bent-forward, seated body position as in the underwater weighing. RLV was measured twice in succession within a five minute period. As determined in the Phase 1 study, reliability of RLV measures was r = 0.97 for the 100 subjects. The standard error or measurement was equal to ±47.3 ml.

6. **Arm radiography.** The x-ray technique utilized a kilovoltage of 76, an exposure time of 1/30 second, and 300 milliampers. A standard x-ray apparatus was used; film was Dupont Cronex hi-speed x-ray film developed with a Kodak x-omat 90-second automatic processor. The procedures for arm positioning followed the protocol described by Behnke and Wilmore (2) and published elsewhere (1,5). All films were clear enough for visual determination of the boundaries for muscle, fat and bone, and there were no retakes. Total x-ray exposure was calculated as 10 milliroentgens.

7. **X-ray measurements.** Measurements were made with the film on a table-top screen illuminated with fluorescent lighting. The precise technique for measuring the x-ray at three sites along the bone axis has been published previously (5,7) including a detailed description in the Phase 1 report (6).

8. **Computer processing of x-ray images.** During the Phase 1 study, considerable effort was expended in trying to develop a computerized method to evaluate the x-ray images. We developed a suitable methodology to extract the information regarding x-ray width measures of fat, muscle, bone, medullary cavity, and cortex. A Graf-Pen digitizer (Science Accessories Corporation; Southport, Conn.) with sonic head was interfaced to an Apple III minicomputer with 128K memory. The digitizer was also interfaced with a printer for rapid printing of reports. The X-Y coordinates on the x-ray film were determined by digitizing the widths of fat, muscle, and bone at sites A, B, and C. The process of digitizing the x-ray widths was under software control and was initiated by booting a program called BONES-XRAY developed specifically for this project. This made it fairly simple to go step-by-step in the digitizing process. The

computer code for the BONES-XRAY program appears in the Phase 1 report.

9. Evaluation of relative fitness status by maximal oxygen consumption (max$\dot{V}O_2$). Max$\dot{V}O_2$ was measured by use of a continuous treadmill protocol (8). There were two variations of the treadmill test depending on the apparent fitness status of the subject prior to testing. This determination was made by interviewing the subject about their current level of physical activity and extent of prior exercise training. For the relatively untrained or non-athletic sample, the treadmill procedure was as follows; the initial elevation was 2.5% and treadmill speed was maintained at 6.0 miles per hour. Treadmill elevation was increased every two minutes by 2.5%. For the remaining subjects who were judged to be more "fit", initial treadmill elevation was 7.5%, speed was 6.0 miles per hour, and elevation was increased by 2.5% each two minutes until voluntary termination. Strong verbal encouragement was given throughout the test, especially during the last few minutes when the subject was close to the termination point. The score for max$\dot{V}O_2$ was selected as either the highest score during the last two increments of exercise, or as an average of the last two $\dot{V}O_2$ scores. In almost every case, the last two scores for $\dot{V}O_2$ were used to represent the max$\dot{V}O_2$.

Heart rate was monitored continuously by radiotelemetry during exercise by standard ECG techniques. A three electrode system was used (V_5 position), and hard copy output was obtained with a strip chart recorder. The last six beats of each minute were averaged to constitute a heart rate score for that minute. Ventilation volume was recorded with a digital pneumotach, and expired air samples were analyzed for oxygen and carbon dioxide content by use of Applied Electrochemistry oxygen and carbon dioxide analyzers. Sampling began at approximately 70% of age predicted maximal heart rate, and gas samples were obtained thereafter at 30-second intervals until the completion of the test. Reference gases were calibrated before and after each test by the micro-Scholander technique. Max$\dot{V}O_2$ was expressed in liters per minute (L/min^{-1}) and per kilogram of body weight (ml/kg·min^{-1}). Several days prior to the treadmill test, subjects jogged on the treadmill for five to ten minutes at 6.0 miles per hour. During the practice session, the subjects breathed through the low resistance, high velocity valve. Treadmill grade was also increased by at least two elevations above the initial starting level. This was done so subjects would become accustomed to the experimental procedures.

Following all of the testing, subjects were placed into one of two max$\dot{V}O_2$ categories; a low fitness category for young males was defined as a relative max$\dot{V}O_2$ below 60.0 ml/kg·min^{-1}. For older males, the low fitness category was a max$\dot{V}O_2$ below 50.0 ml/kg·min^{-1}. For young females, the low fitness category was defined as a relative max$\dot{V}O_2$ below 47.9 ml/kg·min^{-1}, and for older females, the low max$\dot{V}O_2$ category was below 42.9 ml/kg·min^{-1}. The range for the categories was selected after ranking the subjects by max$\dot{V}O_2$, and then using a frequency distribution of the max$\dot{V}O_2$ scores to place subjects into low and high max$\dot{V}O_2$ groups. The creation of the two max$\dot{V}O_2$ groups was straightforward and without complications. In all of the comparisons of the high and low fitness groups, the sample size was as follows: young males, low fit (N=31); young males, high fit (N=27); older males, low fit (N=22); older males, high fit (N=20); young females, low fit (N=32); young females, high fit (N=25); older females, low fit (N=20), and older females, high fit (N=16).

Results

Relative Fitness Status. Table 9 presents descriptive data for max$\dot{V}O_2$ (absolute, liters and relative to body weight, ml/kg·min^{-1}), carbon dioxide production ($\dot{V}CO_2$), ventilation volume ($\dot{V}_E$), respiratory exchange ratio (R), and heart rate (HR) at max$\dot{V}O_2$ for young and older males and females. The top half of Table 10 presents the data for max$\dot{V}O_2$ and associated physiological variables for the males in relation to high and low fitness status; the bottom half of the table lists the corresponding data for females grouped into low and high fitness categories.

Comparison of Physical Characteristics of Subjects Grouped by Fitness Status. Table 11 compares the means and standard deviations for the physical characteristics of the male subjects grouped by fitness status. The comparison includes age, height, weight, body density, body fat percentage, absolute fat weight, lean body weight, residual volume, and the lean to fat ratio. The corresponding data for females is presented in Table 12.

TABLE 9. Comparison of max $\dot{V}O_2$ (absolute and relative), carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (R), ventilation volume ($\dot{V}_E$), and heart rate (HR), at max $\dot{V}O_2$ in young and older males and females

Variable	Young Men (N=58)		Older Men (N=42)		Young Women (N=60)		Older Women (N=40)	
	X	SD	X	SD	X	SD	X	SD
Max $\dot{V}O_2$, $L \cdot min^{-1}$	4.38	0.648	3.95	0.437	2.87	0.480	2.45	2.410
Max $\dot{V}O_2$, $ml/kg \cdot min^{-1}$	60.1	7.77	52.4	6.39	47.8	6.53	41.2	6.81
$\dot{V}CO_2$, L/min^{-1}	4.87	0.725	4.43	0.500	3.17	0.582	2.71	0.430
R	1.11	0.055	1.12	0.047	1.10	0.060	1.11	0.114
$\dot{V}_{E_{STPD}}$ at Max $\dot{V}O_2$	120.0	16.60	108.7	14.14	82.4	12.67	73.4	12.57
HR at Max $\dot{V}O_2$	192.8	9.33	190.5	8.16	191.8	8.33	186.3	8.20

TABLE 10. Max $\dot{V}O_2$ (absolute and relative), $\dot{V}_E$, HR, and R at max $\dot{V}O_2$ in males and females classified by fitness category

Variable	Young Males				Older Males			
	Low Fit (N=31)		High Fit (N=27)		Low Fit (N=22)		High Fit (N=20)	
	X	SD	X	SD	X	SD	X	SD
Max $\dot{V}O_2$, L,min	4.09	0.582	4.67	0.586	3.76	0.411	4.14	0.414
Max $\dot{V}O_2$, ml/kg·min^{-l}	53.7	4.05	66.4	4.78	47.1	3.68	57.6	3.49
$\dot{V}_E$ at max, L,min	116.5	17.83	123.6	14.72	102.4	9.59	115.1	15.32
HR at max, bpm	193.3	10.93	192.3	7.61	192.9	6.93	188.0	8.71
R at max	1.14	0.055	1.111	0.052	1.13	0.051	1.111	0.042

Variable	Young Females				Older Females			
	Low Fit (N=32)		High Fit (N=25)		Low Fit (N=20)		High Fit (N=16)	
Max $\dot{V}O_2$	2.45	0.414	3.10	0.455	2.33	0.481	2.61	0.220
Max $\dot{V}O_2$	43.4	3.22	53.5	5.08	36.9	5.12	46.7	4.21
$\dot{V}_E$ at max	78.1	12.36	87.8	11.08	70.8	14.05	76.9	9.70
HR at max	190.4	9.07	193.5	7.06	185.7	8.10	187.1	8.52
R at max	1.10	0.057	1.111	0.064	1.09	0.083	1.14	0.144

TABLE 11. Comparison of physical characteristics of male subjects grouped by fitness status

Variable	Young Men				Older Men			
	Low Fit (N=31)		High Fit (N=27)		Low Fit (N=22)		High Fit (N=20)	
	X	SD	X	SD	X	SD	X	SD
Age, years	23.6	4.24	23.0	3.76	35.0	2.94	35.1	2.97
Height, cm	177.2	6.19	176.6	8.60	179.1	5.70	176.5	5.64
Weight, kg	75.3	8.69	70.4	8.65	79.1	10.42	71.6	6.48
Body Density, $g \cdot cc^{-1}$	1.067	0.011	1.078	0.007	1.054	0.012	1.067	0.010
Body Fat, %	14.1	4.56	9.1	3.19	19.7	5.38	13.8	4.16
Fat Weight, kg	10.8	3.74	6.5	2.57	15.8	5.72	9.8	2.85
Lean Body Weight, kg	64.6	4.79	64.1	7.60	63.4	7.46	61.8	6.77
Residual Volume, L	1.64	0.367	1.60	0.358	2.00	0.492	1.93	0.396
Lean/Fat Ratio	7.501	4.190	13.030	9 .149	4.497	1.807	7.088	3.071

TABLE 12. Comparison of physical characteristics of female subjects grouped by fitness status

Variable	Young Women				Older Women			
	Low Fit		High Fit		Low Fit		High Fit	
	(N=32)		(N=25)		(N=24)		(N=16)	
	X	SD	X	SD	X	SD	X	SD
Age, years	23.7	4.56	21.8	3.97	34.4	2.75	34.1	3.30
Height, cm	167.2	6.63	166.7	4.93	165.9	7.84	164.0	4.95
Weight, kg	61.9	8.70	58.03	8.65	63.6	8.42	55.8	4.15
Body Density	1.047	0.012	1.052	0.017	1.038	0.015	1.050	0.010
Body Fat, %[b] g/ml[a]	22.9	5.20	20.6	7.59	26.8	6.67	21.7	4.50
Fat Weight, kg	13.3	4.57	11.8	4.92	17.2	5.39	12.2	3.23
Lean Body Weight, kg	43.8	5.50	45.2	4.81	46.2	5.56	43.6	2.76
Residual Volume, L	1.23	0.336	1.33	0.311	1.507	0.321	1.530	0.259
Lean/Fat Ratio	3.616	1.258	4.460	2.328	3.022	1.263	3.834	1.189

TABLE 13. Comparison of fatfolds in young and older males and females

Fatfold Site, mm	Young Men (N=58)		Older Men (N=42)		Young Women (N=60)		Older Women (N=40)	
	X	SD	X	SD	X	SD	X	SD
Biceps	4.5	1.28	5.3	2.46	8.9	4.14	9.2	4.15
Abdomen	15.0	6.79	21.1	9.16	16.2	5.92	17.6	6.4
Iliac	13.4	5.94	16.9	7.50	15.3	6.58	11.2	4.45
Thigh	12.1	4.38	15.0	5.67	26.0	6.77	27.1	6.53
Triceps	111.3	4.12	14.2	5.56	19.1	6.00	20.6	4.97
Subscapular	11.0	2.94	13.4	4.86	12.8	5.02	13.2	4.31
Calf	8.0	3.56	9.1	3.74	15.8	5.55	17.0	6.38
Sum 3[a]	26.7	7.64	32.9	11.57	40.8	14.12	42.9	11.21
Sum 5[b]	62.9	21.79	80.6	28.91	89.5	26.93	89.6	21.33
Sum 7[c]	75.3	25.26	95.0	33.31	114.1	34.99	115.8	29.63

[a]Triceps, biceps, subscapular

[b]Triceps, subscapular, iliac, abdomen, thigh

[c]7 fatfolds

Comparison of Fatfolds in Young and Older Males and Females. Table 13 compares the means and standard deviations for seven fatfolds, including the sum of three, five, and seven fatfolds in young and older males and females. Table 14 shows the corresponding data for fatfolds for males grouped by fitness status, and Table 15 displays the fatfold data for females in relation to fitness status.

Comparison of Girths in Young and Older Males and Females. Table 16 compares the means and standard deviations for 14 girths (including an average of the two abdominal girths) and the sum of the 11 basic girths/100 (D) in the young and older males and females. Table 17 shows the corresponding girth data when the males are grouped by fitness status, and Table 18 lists the girth data for females placed into high and low fitness categories.

Comparison of Bone Diameters in Young and Older Males and Females. Table 19 compares the means and standard deviations for nine bone diameters in the young and older males and females. Table 20 presents the corresponding data for bone diameters when the males are grouped by fitness status, and Table 21 shows the bone diameter data for females in relation to fitness category.

Comparison of Ultrasound Subcutaneous Fat in Young and Older Males and Females. Table 22 compares the means and standard deviations for seven ultrasound subcutaneous fat measurements, including the sum of three, four, five. six, and seven ultrasound sites in young and older males and females. Table 23 presents the corresponding data for young and older males grouped by fitness category, and Table 24 presents the ultrasonic data for females grouped by fitness category.

Comparison of Arm Radiographic Data for Young and Older Males and Females. Table 25 compares the means and standard deviations for the arm radiographic data for the young and older males and females. The data include the total widths of muscle, bone, fat, marrow, and cortex. The score for the total is calculated as the sum of the width measurements at sites A, B, and C; also included are the summary data for individual sites A, B, and C.

Comparison of Arm Radiographic Data for Young and Older Males and Females Grouped by Fitness Category. Table 26

TABLE 14. Comparison of fatfolds of male subjects grouped by fitness status

Fatfold Site, mm	Young Men				Older Men			
	Low Fit (N=31)		High Fit (N=27)		Low Fit (N=22)		High Fit (N=20)	
	X	SD	X	SD	X	SD	X	SD
Biceps	5.0	1.41	3.8	0.71	6.3	2.97	4.2	0.98
Abdomen	18.4	7.20	11.1	3.36	26.4	8.14	15.3	6.31
Iliac	16.2	6.26	10.3	3.65	21.2	7.35	12.3	4.29
Thigh	13.8	4.87	10.3	2.82	17.3	5.96	12.4	4.06
Triceps	13.4	4.14	8.8	2.40	16.8	5.93	11.2	3.26
Subscapular	12.6	3.01	9.2	1.44	16.1	5.14	10.6	2.24
Calf	9.3	3.79	6.6	2.01	9.9	4.21	8.2	2.98
Sum 3[a]	31.0	7.63	21.8	3.74	39.2	12.09	26.1	5.67
Sum 5[b]	74.3	22.33	49.7	11.4	97.8	26.89	61.8	16.98
Sum 7[c]	88.6	25.89	60.1	13.19	114.0	32.52	74.2	18.73

[a]Triceps, biceps, subscapular

[b]Triceps, subscapular, iliac, abdomen, thigh

[c]7 fatfolds

TABLE 15. Comparison of fatfolds of female subjects grouped by fitness status

Fatfold Site, mm	Young Women				Older Women			
	Low Fit (N=32)		High Fit (N=25)		Low Fit (N=24)		High Fit (N=16)	
	X	SD	X	SD	X	SD	X	SD
Biceps	10.1	4.36	7.1	3.13	10.5	4.58	7.1	2.26
Abdomen	18.1	5.77	13.6	5.20	19.7	6.86	14.6	4.17
Iliac	16.5	6.85	13.7	5.95	12.7	4.83	8.9	2.52
Thigh	29.1	5.68	21.7	5.74	28.4	6.99	25.1	5.38
Triceps	21.4	5.67	18.8	4.89	26.7	4.37	18.8	5.44
Subscapular	14.7	5.12	10.2	3.46	14.1	4.55	11.8	3.65
Calf	17.7	4.85	13.0	5.37	18.8	6.74	14.4	4.88
Sum 3[a]	46.3	13.95	33.2	10.50	46.4	11.48	37.8	8.77
Sum 5[b]	99.9	25.39	75.0	22.22	96.6	21.71	79.2	16.31
Sum 7[c]	127.7	33.22	95.2	28.33	125.9	30.30	100.7	21.61

[a]Triceps, biceps, subscapular

[b]Triceps, subscapular, iliac, abdomen, thigh

[c]7 fatfolds

TABLE 16. Comparison of girths for young and older men and women

Variable, cm	Young Men (N=58)		Older Men (N=42)		Young Women (N=60)		Older Women (N=40)	
	X	SD	X	SD	X	SD	X	SD
Neck	38.0	1.90	38.1	1.87	32.2	1.64	32.3	1.98
Shoulder	115.2	6.90	114.5	6.12	103.6	6.51	102.8	5.01
Chest	96.8	6.83	97.6	6.69	89.0	6.10	89.0	5.85
Waist[a]	79.9	5.23	83.7	6.96	69.9	5.51	71.8	5.67
Abdomen[b]	81.4	5.51	86.4	7.53	77.1	5.87	80.3	7.31
Abd. Ave.[c]	80.6	5.36	85.0	7.31	73.5	5.44	76.0	6.29
Buttocks	97.9	5.57	99.2	5.63	96.6	6.06	97.7	5.21
Arm Ext	29.2	2.66	29.3	2.38	25.6	2.43	26.2	2.26
Arm Flex	33.3	3.08	32.9	2.59	27.8	2.55	28.1	2.19
Forearm	27.4	2.12	27.6	1.36	23.6	1.64	23.9	1.14
Wrist	17.1	0.94	17.1	0.73	15.3	1.23	15.1	0.56
Thigh	56.2	3.45	57.1	3.50	56.6	4.46	57.0	38.89
Knee	37.0	1.80	37.6	1.70	36.1	2.37	36.4	2.21
Calf	37.1	2.05	37.5	1.97	35.4	2.69	35.0	2.35
Ankle	22.4	1.33	22.3	1.53	21.3	1.35	21.1	1.28
D[d]	621.1	33.27	628.4	32.35	578.9	35.31	582.7	30.33

[a]natural waist
[b]level of umbilicus
[c]average of waist and abdomen
[d]sum of shoulder, chest, abd. ave., buttocks, arm flex, forearm, wrist, thigh, knee, calf, ankle

TABLE 17. Comparison of girths for young and older males grouped by fitness status

Variable, cm	Young Men				Older Men			
	Low Fit (N=31)		High Fit (N=27)		Low Fit (N=22)		High Fit (N=20)	
	X	SD	X	SD	X	SD	X	SD
Neck	38.2	2.06	37.9	1.71	38.7	1.53	37.3	1.98
Shoulder	117.1	6.82	112.9	6.40	116.1	6.85	112.8	4.80
Chest	98.7	7.06	94.7	6.01	99.8	7.57	95.2	4.65
Waist[a]	81.5	5.59	77.9	4.09	86.9	7.26	80.2	4.64
Abdomen[b]	83.4	5.83	79.0	4.05	90.1	7.85	82.4	4.58
Abd. Ave.[c]	82.4	5.77	78.5	4.01	88.5	7.50	81.1	4.76
Buttocks	98.9	5.47	96.8	5.58	101.4	6.49	96.9	3.23
Arm Ext	30.0	2.42	28.4	2.71	30.1	2.59	28.5	1.90
Arm Flex	33.9	2.92	32.7	3.16	33.5	2.90	32.4	2.13
Forearm	27.9	1.93	27.0	2.26	27.9	1.29	27.2	1.40
Wrist	17.2	1.04	16.8	0.77	17.1	0.69	17.1	0.78
Thigh	57.3	3.54	55.0	2.95	58.4	3.72	55.7	2.60
Knee	37.2	1.73	36.9	1.89	38.0	1.67	37.2	1.67
Calf	37.5	2.12	36.7	1.89	37.7	2.17	37.4	1.78
Ankle	22.7	1.46	22.0	1.09	22.2	1.91	22.5	0.98
D[d]	630.8	33.50	610.0	29.85	640.5	35.76	615.2	22.23

[a]natural waist
[b]level of umbilicus
[c]average of waist and abdomen
[d]sum of shoulder, chest, abd. ave., buttocks, arm flex, forearm, wrist, thigh, knee, calf, ankle

TABLE 18. Comparison of girths for young and older females grouped by fitness status

Variable, cm	Young Women				Older Women			
	Low Fit (N=32)		High Fit (N=25)		Low Fit (N=24)		High Fit (N=16)	
	X	SD	X	SD	X	SD	X	SD
Neck	32.4	1.39	31.8	1.91	32.5	2.31	31.8	1.29
Shoulder	105.1	5.60	101.4	7.18	104.3	5.15	100.5	3.87
Chest	89.9	5.45	87.7	6.80	90.7	6.26	86.3	4.03
Waist[a]	70.9	4.94	68.5	6.04	74.1	5.66	68.0	3.00
Abdomen[b]	78.1	5.89	75.7	5.66	83.0	7.64	75.9	4.09
Abd. Ave.[c]	74.5	5.28	72.2	5.49	78.6	6.43	71.9	3.24
Buttocks	98.1	5.54	94.5	6.26	99.9	5.11	94.5	3.48
Arm Ext	26.4	1.91	24.6	2.72	26.7	2.47	25.3	1.62
Arm Flex	28.4	2.04	26.8	2.91	28.7	2.33	27.3	1.69
Forearm	23.9	1.48	23.2	1.79	24.2	1.29	23.6	0.78
Wrist	17.2	1.04	16.8	0.77	17.1	0.69	17.1	0.78
Thigh	57.6	4.13	55.2	4.62	58.2	4.00	55.2	2.99
Knee	36.5	2.43	35.5	2.19	37.1	2.26	35.3	1.72
Calf	37.5	2.12	36.7	1.89	37.7	2.17	37.4	1.78
Ankle	21.3	1.44	21.4	1.24	21.4	1.35	20.6	1.03
D[d]	586.5	31.82	568.1	37.76	593.8	30.35	565.0	20.84

[a]natural waist
[b]level of umbilicus
[c]average of waist and abdomen
[d]sum of shoulder, chest, abd. ave., buttocks, arm flex, forearm, wrist, thigh, knee, calf, ankle

TABLE 19. Comparison of bone diameters for young and older men and women

Variable, cm	Young Men (N=58)		Older Men (N=42)		Young Women (N=60)		Older Women (N=40)	
	X	SD	X	SD	X	SD	X	SD
Biacromial	39.7	2.46	39.4	1.33	35.9	1.57	35.7	1.55
Bideltoid	46.1	2.45	46.1	1.83	41.7	2.62	41.2	2.19
Chest	29.2	2.09	29.4	1.96	25.6	1.75	25.6	1.65
Biiliac	27.2	1.98	28.3	1.78	27.2	1.50	27.9	1.63
Bitroch	31.3	1.98	32.2	1.44	31.2	1.78	31.4	1.38
Elbow[a]	13.3	0.43	13.3	0.38	11.5	0.35	11.5	0.28
Wrist	10.8	0.33	10.8	0.31	9.4	0.32	9.3	0.24
Knee	17.3	0.57	17.7	0.54	16.6	0.70	16.8	0.60
Ankle	13.3	0.33	13.2	0.33	11.9	0.35	11.9	0.31

[a]Values for elbow, wrist, knee, and ankle are the sum of right and left sides ($P > .05$ for all right and left paired comparisons for men and women)

TABLE 20. Comparison of bone diameters for young and older males grouped by fitness status

Variable, cm	Young Men				Older Men			
	Low Fit (N=31)		High Fit (N=27)		High Fit (N=22)		Low Fit (N=22)	
	X	SD	X	SD	X	SD	X	SD
Biacromial	40.4	2.30	38.9	2.47	39.3	1.39	39.5	1.30
Bideltoid	46.9	2.42	45.2	2.20	45.4	1.68	46.7	1.77
Chest	29.7	2.36	28.7	1.63	29.0	1.24	29.9	2.39
Biiliac	27.4	2.29	27.1	1.59	27.7	1.20	28.9	2.04
Bitroch	31.6	1.69	30.8	2.21	31.8	1.24	32.7	1.51
Elbow[a]	13.4	0.40	13.2	0.45	13.3	0.38	13.4	0.39
Wrist	10.9	0.36	10.7	0.30	10.8	0.31	10.8	0.31
Knee	17.5	0.55	17.0	0.58	17.5	0.61	17.8	0.46
Ankle	13.4	0.32	13.1	0.32	13.2	0.32	13.2	0.34

[a]Values for elbow, wrist, knee, and ankle are the sum of right and left sides ($P > .05$ for all right and left paired comparisons for men and women)

TABLE 21. Comparison of bone diameters for young and older females grouped by fitness status

Variable, cm	Young Women				Older Women			
	Low Fit (N=32)		High Fit (N=25)		Low Fit (N=24)		High Fit (N=16)	
	X	SD	X	SD	X	SD	X	SD
Biacromial	35.9	1.54	35.9	1.65	36.0	1.79	35.3	1.03
Bideltoid	42.1	2.06	41.1	3.20	42.0	2.01	40.1	1.98
Chest	25.7	1.27	25.4	2.29	26.2	1.63	24.7	1.20
Biiliac	27.5	1.49	27.0	1.50	28.5	1.47	26.9	1.41
Bitroch	31.4	1.59	30.9	2.02	31.9	1.37	30.7	1.03
Elbow[a]	11.5	0.35	11.3	0.35	11.5	0.27	11.4	0.29
Wrist	9.4	0.31	9.5	0.34	9.2	0.28	9.4	0.17
Knee	16.8	0.71	16.3	0.66	16.9	0.60	16.6	0.61
Ankle	11.9	0.38	12.0	0.29	11.9	0.34	11.8	0.26

[a]Values for elbow, wrist, knee, and ankle are the sum of right and left sides ($P > .05$ for all right and left paired comparisons for men and women)

TABLE 22 . Descriptive statistics for ultrasound measurements of young and older males and females

Ultrasound Site, mm	Males				Females			
	Young (58)		Older (42)		Young (60)		Older (40)	
	X	SD	X	SD	X	SD	X	SD
Biceps	4.3	0.67	4.9	1.70	7.9	5.82	8.3	7.47
Abdomen	10.2	7.40	14.0	8.82	12.6	6.27	16.2	9.40
Iliac	9.5	4.53	12.3	6.72	12.0	5.40	12.4	8.03
Thigh	7.1	1.66	8.2	2.25	12.8	2.87	14.6	5.39
Triceps	7.0	1.89	8.5	2.82	11.7	3.82	13.9	5.68
Subscapula	6.7	1.31	8.1	2.87	8.6	3.60	9.7	6.89
Calf	5.5	1.36	6.4	1.89	9.1	3.03	10.8	4.77
Sum 3 US[a]	18.0	3.21	21.42	5.79	28.2	10.12	32.2	18.16
Sum 4 US[b]	27.5	6.70	33.8	11.68	39.7	13.44	44.6	24.93
Sum 5 US[c]	37.8	13.57	47.7	19.17	52.3	17.88	60.8	32.17
Sum 6 US[d]	44.9	14.73	55.6	19.35	66.4	18.34	76.1	36.73
Sum 7 US[e]	50.4	15.66	62.0	20.48	75.4	20.09	87.1	39.48

[a]Triceps, biceps, subscapula
[b]Sum 3 US + iliac
[c]Sum 4 + abdomen
[d]Sum 5 + thigh
[e]Sum 6 + calf

TABLE 23. Descriptive statistics for ultrasound measurements of young and older male subjects grouped by fitness category

Ultrasound Site, mm	Young Male				Older Male			
	Low Fit (31)		High Fit (27)		Low Fit (22)		High Fit (20)	
	X	SD	X	SD	X	SD	X	SD
Biceps	4.5	0.74	4.0	0.47	5.6	2.06	4.1	0.61
Abdomen	12.5	8.82	7.6	4.11	16.3	10.19	11.4	6.33
Iliac	11.3	5.26	7.4	2.12	15.3	8.05	9.1	2.26
Thigh	7.7	1.71	6.5	1.35	9.1	2.20	7.2	1.88
Triceps	7.8	2.05	6.2	1.28	9.7	3.06	7.1	1.80
Subscapula	7.4	1.25	5.9	0.86	9.1	2.39	7.0	3.00
Calf	5.9	1.59	5.1	0.88	6.8	2.27	5.9	1.26
Sum 3 US	19.7	3.21	16.1	1.88	24.3	5.94	18.2	3.56
Sum 4 US	31.0	7.41	23.5	3.54	39.6	13.08	27.4	4.76
Sum 5 US	43.5	15.28	31.1	6.97	55.9	22.53	38.8	8.38
Sum 6 US	51.1	16.42	37.8	8.17	64.4	21.88	46.0	9.66
Sum 7 US	57.0	17.49	42.9	8.64	71.2	23.24	51.9	10.20

TABLE 24. Descriptive statistics for ultrasound measurements of young and older female subjects grouped by fitness category

Ultrasound Site, mm	Young Females				Older Females			
	Low Fit (32)		High Fit (25)		Low Fit (24)		High Fit (16)	
	X	SD	X	SD	X	SD	X	SD
Biceps	8.6	6.04	6.9	5.45	8.8	6.94	6.0	3.69
Abdomen	13.9	6.15	10.9	6.11	17.7	10.09	12.5	4.25
Iliac	13.4	6.25	10.1	3.23	13.4	7.75	8.9	2.57
Thigh	14.1	2.55	11.1	2.33	14.3	3.40	13.0	2.39
Triceps	12.8	3.74	10.1	3.42	13.7	2.77	12.4	2.63
Subscapula	9.6	3.48	7.3	3.36	9.3	2.96	7.9	2.48
Calf	9.8	2.94	8.0	2.87	11.9	5.68	9.0	2.52
Sum 3 US	31.0	9.78	24.2	9.38	31.8	9.60	26.3	5.61
Sum 4	43.6	13.49	34.4	11.63	45.2	15.62	35.2	6.99
Sum 5	57.5	17.25	45.3	16.51	62.9	23.39	47.7	8.78
Sum 6	73.1	17.74	57.2	15.15	77.8	25.28	61.4	10.23
Sum 7	82.9	19.52	65.2	16.22	89.7	29.91	70.4	11.82

TABLE 25. Comparison of arm radiographic data for young and older males and females

Variable[a]	Males				Females			
	Young (N=53)		Older (N=36)		Young (N=60)		Older (N=40)	
	X	SD	X	SD	X	SD	X	SD
Total Muscle	212.97	25.404	205.52	21.164	164.64	22.670	163.62	17.286
Total Bone	72.48	1.963	71.92	1.896	63.19	1.700	61.52	1.355
Total Fat	38.14	12.438	51.76	19.428	63.37	22.463	74.33	21.088
Total Cortex	29.77	4.053	27.90	3.301	25.58	3.462	24.40	2.764
Total Marrow	42.61	6.188	44.02	4.63	37.61	4.564	37.12	4.042
Cortex/Marrow	0.72	0.178	0.64	0.108	0.69	0.153	0.67	0.102
Site A								
Muscle	84.19	9.107	82.52	6.901	67.09	8.184	67.35	6.433
Bone	25.71	2.166	25.27	2.024	22.29	2.069	21.43	1.511
Fat	11.42	4.942	17.40	7.754	20.35	9.294	23.95	7.864
Marrow	17.37	2.766	17.66	2.200	14.84	2.109	14.22	1.663
Cortex	8.34	1.623	7.61	1.321	7.45	1.290	7.20	1.289
Site B								
Muscle	64.43	9.097	63.04	8.606	49.97	7.962	50.83	9.015
Bone	25.34	2.142	25.10	2.003	21.97	1.666	21.64	1.496
Fat	16.34	5.808	20.81	7.475	24.19	7.592	27.81	8.722
Marrow	14.29	2.447	14.90	2.053	12.75	1.999	12.91	2.183
Cortex	10.94	1.636	10.20	1.506	9.22	1.580	8.73	1.313
Site C								
Muscle	64.36	9.240	59.96	7.547	47.58	8.541	45.44	5.918
Bone	21.43	1.580	21.55	1.661	18.93	1.366	18.45	1.057
Fat	10.37	3.307	13.54	5.376	18.82	6.632	22.58	7.215
Marrow	10.95	2.449	11.46	1.394	10.02	1.297	9.99	1.180
Cortex	10.49	2.268	10.09	1.498	8.91	1.331	8.46	0.967
3 Arm Girths								
Site A	40.50	3.725	41.73	3.595	35.53	3.130	36.39	2.276
Site B	30.70	2.790	30.89	2.916	26.76	2.536	27.69	2.313
Site C	29.24	3.198	29.37	2.475	25.45	2.450	26.24	2.063

[a]All measurements in mm except 3 arm girths (cm) and cortex/marrow (%)

TABLE 26. Comparison of arm radiographic data for young and older males grouped by fitness status

Variable[a]	Young Males				Older Males			
	Low Fit (N=27)		High Fit (N=26)		Low Fit (N=l7)		High Fit (N=16)	
	X	SD	X	SD	X	SD	X	SD
Total Muscle	214.59	23.900	210.54	25.889	207.38	26.980	203.78	14.168
Total Bone	71.84	1.795	72.95	2.133	71.40	1.967	71.84	1.654
Total Fat	45.10	11.625	31.66	9.004	60.19	18.667	39.91	9.311
Total Cortex	29.87	3.748	29.66	4.420	27.63	3.642	28.23	3.079
Total Marrow	41.97	4.811	43.28	7.392	43.78	4.580	43.57	4.011
Cortex/Marrow	0.73	0.143	0.72	0.210	0.64	0.107	0.66	0.108
Site A								
Muscle	84.80	9.116	83.18	8.587	82.18	7.662	82.88	6.472
Bone	25.43	1.998	26.00	2.333	25.45	2.282	24.86	1.544
Fat	14.42	4.253	8.68	3.785	21.09	8.170	12.74	3.584
Marrow	17.05	2.390	17.71	3.121	17.74	2.340	17.26	1.732
Cortex	8.38	1.300	8.29	1.928	7.71	1.439	7.60	1.223
Site B								
Muscle	65.61	8.197	63.20	9.957	63.55	11.250	62.44	5.213
Bone	25.14	1.800	25.34	2.480	24.74	1.970	25.34	2.036
Fat	18.76	5.445	13.82	5.138	24.09	6.812	16.15	3.746
Marrow	14.15	2.080	14.44	2.813	14.42	1.581	15.17	2.291
Cortex	10.99	1.806	10.90	1.473	10.32	1.571	10.17	1.467
Site C								
Muscle	64.17	8.497	64.17	9.583	61.64	9.530	58.45	4.640
Bone	21.27	1.587	21.61	1.585	21.21	1.650	21.64	1.382
Fat	11.91	3.335	9.16	2.106	15.02	4.881	11.03	3.707
Marrow	10.77	2.194	11.14	2.720	11.62	1.424	11.14	1.262
Cortex	10.50	2.263	10.47	2.318	9.60	1.457	10.50	1.423
3 Arm Girths								
Site A	40.86	3.338	40.08	4.150	42.81	3.187	40.54	3.725
Site B	31.46	2.619	29.84	2.773	31.74	3.016	29.95	2.556
Site C	29.88	2.599	28.50	3.681	30.25	2.642	28.40	1.902

[a]All measurements in mm except 3 arm girths (cm) and cortex/marrow (%)

compares the means and standard deviations for the radiogrammetric data listed in Table 25 for the low fit and high fit males, and Table 27 shows the corresponding data for the low and high fit females.

Intercorrelations Between Radiogrammetric Widths for the Total Sample of Males and Females (N=176), Including the Relationship with Densitometry. Table 28 presents the matrix of intercorrelations between the various radiogrammetric widths for the total sample of males and females, including the relationship with percent body fat (densitometry). As would be expected, the intercorrelations were high between the fat widths (r = .783 to .952) and the muscle widths (r = .824 to .933). Of course, the correlations between the individual widths and the sum of the widths (TOT) are highest because the data used to generate the relationship with TOT include the scores from one of the width sites. The intercorrelations between the fat and muscle sites, muscle and bone sites, and fat and bone sites, were all below 50 percent common variance. For example, FAT A correlated r = -.359 with MUS A, FAT B correlated r = -.30 with MUS B, and FAT C correlated r = -.505 with MUS C.

The most encouraging relationships were between the individual x-ray FAT sites and body fat calculated from densitometry. The highest correlation was between FAT TOT and body fat, density (r = .884; r^2 = .781). The correlations were low and negative between the various muscle widths and body fat, density (r = -.303 to -.490). The same was true for body fat, density and MAR TOT (r = -.312) and COR TOT (r = -.444). There was no relationship between MAR TOT and COR TOT (r = -.079).

Because of an obvious age and gender influence on body composition, the same analysis presented in Table 28 was done separately for the subgroups of young and older males and females. These results are presented in Table 29 (young males), Table 30 (older males), Table 31 (young females), and Table 32 (older females). Nearly the same pattern of correlations emerged for the age and gender analysis compared with the analysis for the total sample shown in Table 28. The intercorrelations among the FAT and MUS sites were relatively high, as were the correlations between FAT TOT and body fat estimated from densitometry. The following correlations were obtained between FAT TOT and body fat, density; young males (r = .795; r^2 = .632 in Table 29), older males (r = .864;

TABLE 27. Comparison of arm radiographic data for young and older females grouped by fitness status

Variable[a]	Young Females				Older Females			
	Low Fit (N=35)		High Fit (N=25)		Low Fit (N=24)		High Fit (N=16)	
	X	SD	X	SD	X	SD	X	SD
Total Muscle	167.50	16.543	161.99	19.890	166.03	17.587	160.75	17.603
Total Bone	63.56	1.559	62.32	1.746	62.18	1.399	61.01	1.236
Total Fat	69.59	14.599	52.99	16.295	81.30	22.880	65.66	16.280
Total Cortex	25.42	3.009	25.47	3.929	24.77	2.192	24.14	3.350
Total Marrow	38.15	4.800	36.85	4.366	37.42	4.201	36.87	4.074
Cortex/Marrow	0.68	0.151	0.70	0.162	0.67	0.111	0.67	0.136
Site A								
Muscle	68.46	5.253	65.72	6.139	67.93	6.704	66.60	6.446
Bone	22.53	2.013	21.90	2.143	21.64	1.311	21.33	1.659
Fat	22.11	5.949	16.77	6.697	26.21	8.919	20.85	5.401
Marrow	15.03	2.107	14.51	2.113	14.28	1.758	14.26	1.597
Cortex	7.51	1.360	7.40	1.274	7.36	7.992	7.08	1.309
Site B								
Muscle	50.66	7.012	49.43	8.126	52.39	10.740	49.01	6.680
Bone	22.12	1.558	21.71	1.669	21.81	1.796	21.53	1.060
Fat	27.01	5.396	20.11	5.958	29.79	10.561	25.16	5.459
Marrow	13.04	2.371	12.49	1.439	12.90	2.413	12.93	2.032
Cortex	9.08	1.677	9.22	1.396	8.91	1.098	8.60	1.542
Site C								
Muscle	48.38	6.060	46.83	7.966	45.71	5.938	45.13	6.263
Bone	18.91	1.107	18.71	1.425	18.73	1.091	18.15	0.989
Fat	20.48	4.638	16.11	4.993	25.31	7.078	19.65	6.412
Marrow	10.08	1.204	9.86	1.379	10.23	1.236	9.68	1.109
Cortex	8.83	1.024	8.86	1.559	8.50	0.828	8.47	1.153
3 Arm Girths								
Site A	36.44	3.071	34.29	2.818	37.05	2.402	34.55	1.742
Site B	27.60	2.030	25.60	2.740	28.42	2.423	26.63	1.712
Site C	26.20	2.051	24.43	2.618	26.87	2.190	25.34	1.513

[a]All measurements in mm except 3 arm girths (cm) and cortex/marrow (%)

TABLE 28. Intercorrelations between radiogrammetric widths for the total sample of males and females (N=176), including the relationship with percent body fat (densitometry)

	Variables[a]										
	FAT A	FAT B	FAT C	FAT TOT	MUS A	MUS B	MUS C	MUS TOT	MAR TOT	COR TOT	%Body Fat,Den
FAT A		.831	.837	.952	-.359	-.150	-.313	-.290	-.236	-.292	.854
FAT B			.783	.934	-.267	-.300	-.322	-.314	-.273	-.290	.786
FAT C				.925	-.482	-.292	-.505	-.452	-.361	-.367	.848
FAT TOT					-.388	-.262	-.398	-.370	-.306	-.332	.884
MUS A						.820	.824	.933	.434	.573	-.490
MUS B							.867	.949	.388	.555	-.303
MUS C								.951	.455	.605	-.469
MUS TOT									.451	.612	-.444
MAR TOT										-.079	-.312
COR TOT											-.444

[a]FAT A, B, C = sum of fat widths at sites A, B, and C. MUS A, B, C = sum of muscle widths at sites A, B, and C. FAT TOT, MUS TOT, MAR TOT, and COR TOT = sum of total fat, muscle, marrow, and cortex widths, respectively, at sites A + B + C. An r = .254 is significant at p < .01

[b]Siri conversion; % fat = 495/Den - 450

TABLE 29. Intercorrelations between radiogrammetric widths for young males (N=53), including the relationship with percent body fat (densitometry)

	Variables[a]										
	FAT A	FAT B	FAT C	FAT TOT	MUS A	MUS B	MUS C	MUS TOT	MAR TOT	COR TOT	% Body Fat,Den[b]
FAT A		.681	.698	.895	-.049	.155	.014	.044	-.033	-.036	.783
FAT B			.679	.913	.245	.076	.041	.130	-.097	-.008	.643
FAT C				.849	.121	.053	-.168	.001	.028	-.174	.715
FAT TOT					.126	.111	-.017	.079	-.052	-.062	.795
MUS A						.786	.656	.883	.078	.343	.026
MUS B							.870	.962	.147	.331	.123
MUS C								.916	.184	.303	-.007
MUS TOT									.149	.354	.052
MAR TOT										-.501	.043
COR TOT											-.168

[a]FAT A, B, C = sum of fat widths at sites A, B, and C. MUS A, B, C = sum of muscle widths at sites A, B, and C. FAT TOT, MUS TOT, MAR TOT, and COR TOT = sum of total fat, muscle, marrow, and cortex widths, respectively, at sites A + B + C. An $r = .352$ is significant at $p < .01$

[b]Siri conversion; % fat = 495/Den - 450

TABLE 30. Intercorrelations between radiogrammetric widths for the older males (N=33), including the relationship with percent body fat (densitometry)

	Variables[a]										
	FAT A	FAT B	FAT C	FAT TOT	MUS A	MUS B	MUS C	MUS TOT	MAR TOT	COR TOT	% Body Fat,Den[b]
FAT A		.794	.839	.946	.090	.490	.403	.372	.177	-.166	.832
FAT B			.828	.934	.204	.281	.314	.293	-.052	-.113	.778
FAT C				.933	-.041	.411	.208	.176	-.025	-.182	.823
FAT TOT					.105	.389	.344	.315	.049	-.161	.864
MUS A						.737	.692	.872	.208	.570	-.145
MUS B							.853	.950	.305	.418	.216
MUS C								.928	.135	.596	.116
MUS TOT									.240	.568	.082
MAR TOT										.184	.085
COR TOT											-.376

[a]FAT A, B, C = sum of fat widths at sites A, B, and C. MUS A, B, C = sum of muscle widths at sites A, B, and C. FAT TOT, MUS TOT, MAR TOT, and COR TOT = sum of total fat, muscle, marrow, and cortex widths, respectively, at sites A + B + C. An $r = .447$ is significant at $p < .01$

[b]Siri conversion; % fat = 495/Den - 450

TABLE 31. Intercorrelations between radiogrammetric widths for young females (N=60), including the relationship with percent body fat (densitometry)

	Variables[a]										
	FAT A	FAT B	FAT C	FAT TOT	MUS A	MUS B	MUS C	MUS TOT	MAR TOT	COR TOT	% Body Fat,Den[b]
FAT A		.818	.799	.942	.116	.247	.187	.210	-.066	.127	.791
FAT B			.797	.939	.212	.054	.158	.151	-.026	-.011	.756
FAT C				.916	.042	.381	.067	.106	-.059	.115	.762
FAT TOT					.139	.166	.153	.171	-.053	.080	.825
MUS A						.664	.612	.826	.243	.174	.080
MUS B							.820	.937	.213	.400	.180
MUS C								.916	.337	.368	.135
MUS TOT									.294	.361	.151
MAR TOT										-.371	.007
CAR TOT											-.077

[a]FAT A, B, C = sum of fat widths at sites A, B, and C. MUS A, B, C = sum of muscle widths at sites A, B, and C. FAT TOT, MUS TOT, MAR TOT, and COR TOT = sum of total fat, muscle, marrow, and cortex widths, respectively, at sites A + B + C. An $r = .325$ is significant at $p < .01$

[b]Siri conversion; % fat = 495/Den - 450

TABLE 32. Intercorrelations between radiogrammetric widths for the older females (N=40), including the relationship with percent body fat (densitometry)

	Variables[a]										
	FAT A	FAT B	FAT C	FAT TOT	MUS A	MUS B	MUS C	MUS TOT	MAR TOT	COR TOT	% Body Fat,Den[b]
FAT A		.758	.761	.941	-.099	.094	-.104	-.023	-.108	-.038	.799
FAT B			.554	.881	.000	.499	-.162	-.239	-.098	-.011	.660
FAT C				.850	-.169	.220	-.295	-.049	-.306	-.305	.767
FAT TOT					-.094	-.036	-.205	-.124	-.184	-.006	.828
MUS A						.454	.468	.769	-.053	.417	.061
MUS B							.496	.860	-.216	.352	.271
MUS C								.775	-.088	.424	.075
MUS TOT									-.163	.484	.190
MAR TOT										-.586	-.252
COR TOT											.089

[a]FAT A,B,C = sum of fat widths at sites A, B, and C. MUS A, B, C = sum of muscle widths at sites A, B, and C. FAT TOT, MUS TOT, MAR TOT, and COR TOT = sum of total fat, muscle, marrow, and cortex widths, respectively, at sites A + B + C. An r = .393 is significant at p < .01

[b]Siri conversion; % fat = 495/Den - 450

r^2 = .746 in Table 30), young females (r = .825; r^2 = .681 in Table 31), and older females (r = .828; r^2 = .686 in Table 32). The correlations between body fat, density and the MUS, COR, and MAR widths were low and non-significant.

Intercorrelations Between the Fat and Muscle Radiogrammetric Widths and Seven Fatfolds for the Total Sample of Males and Females. Table 33 shows the intercorrelations between the FAT and MUS x-ray widths and the seven fatfolds for the combined sample of males and females. Except for the correlation between FAT C and iliac fatfold (r = .295), all of the remaining correlations were significant between the FAT widths and the fatfolds. The highest correlations for the individual FAT widths occurred for FAT C and thigh (r = .846) and FAT C and tricep (r = .828). For FAT TOT, the highest correlation was r = .873 with triceps, followed by thigh (r = .821) and calf (r = .818).

Because of an age and gender influence on body composition, the correlational analysis was done separately for the young and older subgroups of males and females. The data are presented in Table 34 for young males, Table 35 for older males, Table 36 for young females, and Table 37 for older females. For young males, the highest correlation occurred between FAT TOT and triceps (r = .779); for older males, the highest correlation occurred between FAT TOT and abdomen (r = .741). For the females, the pattern of the correlations between FAT TOT and fatfolds was the same as for the males, but the absolute values were larger. For young females, the correlations were r = .866 between FAT TOT and triceps, and r = .828 between FAT A and the abdomen fatfold. For the older females, the highest correlations occurred between FAT TOT and the calf fatfold (r = .831) and triceps fatfold (r = .756).

Intercorrelations Between Fat Radiogrammetric Widths and Various Combinations of Fatfolds for the Total Sample of Males and Females. Various combinations of fatfolds (FF) were summed and intercorrelated with FAT TOT and sites FAT A, FAT B, and FAT C. As shown in Table 38, the increase in the correlations is not really very great when more than three FF are summed (triceps, biceps, scapula). The sum of four, five and six FF yielded <u>lower</u> correlations with the criterion FAT sites than the sum of three FF. The addition of a seventh FF increased the magnitude of the correlations only slightly (3.0% for FAT B, but less than 1.2% for FAT

TABLE 33. Intercorrelations between the fat and muscle radiogrammetric widths and seven fatfolds for the total sample of males and females (N=176)

	Variables[a]						
	Biceps	Abdomen	Iliac	Thigh	Tricep	Subscap	Calf
FAT A	.776	.627	.538	.747	.831	.675	.744
FAT B	.680	.572	.450	.728	.797	.573	.744
FAT C	.786	.438	.295	.846	.828	.514	.821
FAT TOT	.795	.587	.463	.821	.873	.630	.818
MUS A	-.408	.033	.092	-.564	-.379	.024	-.453
MUS B	-.232	.124	.161	-.403	-.249	-.145	-.358
MUS C	-.384	.035	.099	-.523	-.390	-.006	-.453
MUS TOT	-.361	.068	.124	-.526	-.360	.057	-.447

[a]The fatfolds were computed as an average of 3 measurements per site. An $r = .254$ is significant at $p < .01$

TABLE 34. Intercorrelations between the fat and muscle radiogrammetric widths and seven fatfolds for the young males (N=53)

	Variables[a]						
	Biceps	Abdomen	Iliac	Thigh	Tricep	Subscap	Calf
FAT A	.696	.750	.718	.608	.678	.677	.658
FAT B	.594	.657	.584	.493	.678	.536	.537
FAT C	.587	.582	.582	.633	.756	.606	.729
FAT TOT	.705	.754	.708	.634	.779	.674	.698
MUS A	-.020	-.024	.018	.099	.138	.150	.129
MUS B	.080	.093	.171	.188	.082	.224	.131
MUS C	.007	.069	.087	.043	-.092	.073	-.062
MUS TOT	.025	.050	.101	.120	.046	.162	.072

[a]The fatfolds were computed as an average of 3 measurements per site. An $r = .354$ is significant at $p < .01$

TABLE 35. Intercorrelations between the fat and muscle radiogrammetric widths and seven fatfolds for the older males (N=33)

	Variables[a]						
	Biceps	Abdomen	Iliac	Thigh	Tricep	Subscap	Calf
FAT A	.608	.660	.749	.422	.696	.477	.562
FAT B	.615	.751	.611	.578	.526	.390	.529
FAT C	.648	.670	.513	.633	.697	.264	.637
FAT TOT	.662	.741	.684	.565	.678	.419	.606
MUS A	-.130	.399	.221	-.092	-.375	.363	.130
MUS B	.075	.596	.410	-.054	-.050	.361	.375
MUS C	.019	.484	.351	-.010	-.087	.282	.357
MUS TOT	.005	.545	.364	-.055	-.174	.365	.322

[a]The fatfolds were computed as an average of 3 measurements per site. An $r = .433$ is significant at $p < .01$

TABLE 36. Intercorrelations between the fat and muscle radiogrammetric widths and seven fatfolds for the young females (N=55)

	Variables[a]						
	Biceps	Abdomen	Iliac	Thigh	Tricep	Subscap	Calf
FAT A	.823	.828	.733	.747	.818	.749	.650
FAT B	.708	.755	.668	.716	.796	.775	.636
FAT C	.733	.679	.554	.801	.811	.654	.726
FAT TOT	.811	.814	.707	.805	.866	.784	.714
MUS A	.024	.142	.103	.224	.175	.222	.149
MUS B	.077	.156	.009	.330	.269	.116	.096
MUS C	.038	.092	-.040	.252	.198	.079	.062
MUS TOT	.054	.145	.021	.304	.242	.149	.111

[a]The fatfolds were computed as an average of 3 measurements per site. An $r = .339$ is significant at $p < .01$

TABLE 37. Intercorrelations between the fat and muscle radiogrammetric widths and seven fatfolds for the older females (N=35)

	Variables[a]						
	Biceps	Abdomen	Iliac	Thigh	Tricep	Subscap	Calf
FAT A	.706	.664	.739	.626	.702	.573	.741
FAT B	.461	.501	.585	.643	.668	.253	.776
FAT C	.700	.535	.502	.700	.650	.439	.698
FAT TOT	.689	.634	.685	.735	.756	.466	.831
MUS A	.092	.113	.210	-.264	.102	.127	-.131
MUS B	.416	.289	.287	-.088	.092	.483	-.101
MUS C	.093	.114	.194	-.138	.012	.153	-.058
MUS TOT	.283	.232	.294	-.191	.090	.351	-.121

[a]The fatfolds were computed as an average of 3 measurements per site. An $r = .418$ is significant at $p < .01$

TABLE 38. Intercorrelations between fat radiogrammetric widths and various combinations of fatfolds (FF) for the total sample of males and females (N=176)

	Variables			
	FAT A	FAT B	FAT C	FAT TOT
Sum 3 FF[a]	.862	.783	.808	.873
Sum 4 FF[b]	.828	.739	.701	.809
Sum 5 FF[c]	.842	.764	.733	.841
Sum 6 FF[d]	.853	.782	.763	.855
Sum 7 FF[e]	.869	.807	.804	.883

[a]Triceps, biceps, scapula

[b]Sum 3 FF + iliac

[c]Triceps, thigh, scapula, iliac, abdomen

[d]Triceps, scapula, iliac, abdomen, thigh, biceps

[e]Sum 6 FF + calf

A, FAT C, and FAT TOT). The correlation was $r = .873$ ($r^2 = .762$) between the Sum 3 FF and FAT TOT (Table 38).

Relationship Between Fat Radiogrammetric Widths and Fatfolds for Males and Females. Table 39 lists the correlations between the FAT radiogrammetric widths and various combinations of fatfolds for the young and older males, and Table 40 presents the corresponding data for the young and older females.

Relationship Between Fat Radiogrammetric Widths and Ultrasound Subcutaneous Fat Sites. Table 41 presents the intercorrelations between the FAT radiogrammetric widths and various combinations of ultrasound subcutaneous fat for the total sample of males and females. Table 42 lists the corresponding data for the young and older males, and Table 43 presents the data for the young and older females.

Relationship Between Fat and Muscle Radiogrammetric Widths and Seven Ultrasound Sites for the Total Sample of Males and Females. Table 44 lists the correlations between the four FAT,x-ray and four muscle widths and the seven ultrasound *sites for the total sample of males and females. It is noteworthy that* the correlations are all positive between the FAT,x-ray and ultrasound sites, and negative between the MUS and ultrasound sites. The correlations average $r = .603$ between the FAT A, B, and C sites and the seven ultrasound measures, but $r = -.237$ between the MUS A, B, and C sites and the corresponding ultrasound sites.

Computation of k Constants Based on Age and Gender. Table 45 shows the basic mean data for 3F, % body fat (density), and sum of fat widths (expressed in cm) that were used to compute the k constants listed in the last column of the table for the young and older males and females. For comparison purposes, the basic data and k values are included from the Phase 1 experiment, including the original Behnke data and k values. The equation to compute k is as follows: k = sum fat widths/3F x % body fat, where 3F = $\sqrt{}$wt,kg/ht,dm, and the sum of fat widths, 3F, and % body fat were the mean values for each subgroup. For example, the k value for the total sample of young males was computed as k = 38.135 (sum of fat widths)/6.094 (3F) x 11.79 (% body fat) = .05308. The k values for the other subgroups were computed in similar fashion.

TABLE 39. Intercorrelations between the fat radiogrammetric widths and various combinations of fatfolds for young and older males

Fatfolds[a]	Group[b]	FAT A	FAT B	FAT C	FAT TOT
Biceps	YM	.696	.594	.587	.705
	OM	.608	.615	.648	.662
Abdomen	YM	.750	.657	.582	.754
	OM	.660	.751	.670	.741
Iliac	YM	.718	.584	.582	.708
	OM	.791	.698	.687	.780
Thigh	YM	.608	.493	.633	.634
	OM	.583	.596	.758	.673
Tricep	YM	.678	.678	.756	.780
	OM	.825	.738	.813	.843
Subscap	YM	.677	.536	.606	.674
	OM	.800	.764	.658	.802
Calf	YM	.658	.537	.729	.698
	OM	.573	.600	.762	.671

[a]Each site computed as an average of 3 measurements

[b]YM = young men (N=53); OM = old men (N=33)

TABLE 40. Intercorrelations between the fat radiogrammetric widths and various combinations of fatfolds for young and older females

Fatfolds[a]	Group[b]	FAT A	FAT B	FAT C	FAT TOT
Biceps	YF	.823	.708	.733	.812
	OF	.706	.461	.700	.689
Abdomen	YF	.828	.755	.679	.814
	OF	.664	.501	.535	.634
Iliac	YF	.733	.668	.554	.707
	OF	.739	.585	.502	.685
Thigh	YF	.747	.716	.801	.805
	OF	.626	.643	.700	.735
Tricep	YF	.818	.796	.811	.866
	OF	.701	.668	.650	.756
Subscap	YF	.749	.775	.654	.784
	OF	.573	.253	.439	.466
Calf	YF	.650	.636	.726	.714
	OF	.741	.776	.698	.831

[a]Each site computed as an average of 3 measurements

[b]YM = young females (N=55); OF = old females (N=35)

TABLE 41. Intercorrelations between the fat radiogrammetric widths and various combinations of ultrasound subcutaneous fat for the total sample of males and females (N=176)

Ultrasound	FAT A	FAT B	FAT C	FAT TOT
Sum 3 US[a]	.762	.727	.720	.786
Sum 4 US[b]	.806	.739	.667	.792
Sum 5 US[c]	.781	.702	.614	.751
Sum 6 US[d]	.820	.765	.708	.820
Sum 7 US[e]	.832	.784	.739	.841

[a]Triceps, biceps, subscapula

[b]Sum 3 US + iliac

[c]Sum 4 + abdomen

[d]Sum 5 + thigh

[e]Sum 6 + calf

TABLE 42. Intercorrelations between the fat radiogrammetric widths and various combinations of ultrasound subcutaneous fat for young and older males

Ultrasound[a]	Group[b]	FAT A	FAT B	FAT C	FAT TOT
Biceps	YM	.623	.536	.597	.651
	OM	.894	.661	.696	.812
Abdomen	YM	.644	.456	.513	.600
	OM	.570	.417	.328	.486
Iliac	YM	.690	.526	.528	.656
	OM	.749	.611	.513	.684
Thigh	YM	.576	.455	.610	.597
	OM	.422	.578	.633	.565
Tricep	YM	.529	.501	.595	.596
	OM	.696	.526	.697	.678
Subscap	YM	.615	.547	.670	.671
	OM	.477	.390	.264	.419
Calf	YM	.592	.484	.602	.615
	OM	.562	.529	.637	.606

[a]Each site computed as an average of 3 measurements

[b]YM = young men (N=53); OM = old men (N=33)

TABLE 43. Intercorrelations between the fat radiogrammetric widths and various combinations of ultrasound subcutaneous fat for young and older females

Ultrasound[a]	Group[b]	FAT A	FAT B	FAT C	FAT TOT
Bicep	YF	.294	.344	.334	.346
	OF	.594	.566	.422	.596
Abdomen	YF	.382	.346	.405	.405
	OF	.639	.586	.319	.586
Iliac	YF	.716	.665	.554	.704
	OF	.643	.584	.420	.620
Thigh	YF	.607	.651	.694	.693
	OF	.649	.735	.637	.760
Tricep	YF	.691	.739	.731	.770
	OF	.719	.686	.608	.755
Subscap	YF	.519	.555	.275	.496
	OF	.440	.247	.377	.391
Calf	YF	.457	.477	.523	.517
	OF	.729	.755	.620	.792

[a]Each site computed as an average of 3 measurements

[b]YF = young females (N=55); OF = old females (N=35)

TABLE 44. Intercorrelations between the fat and muscle radiogrammetric widths and seven ultrasound subcutaneous fat sites for the total sample of males and females (N=176)

	Ultrasound Sites[a]						
X-Ray	Biceps	Abdomen	Iliac	Thigh	Tricep	Subscap	Calf
FAT A	.484	.577	.655	.708	.772	.541	.687
FAT B	.481	.495	.569	.735	.743	.476	.694
FAT C	.471	.400	.430	.816	.800	.398	.729
FAT TOT	.511	.529	.596	.800	.822	.507	.749
MUS A	-.268	-.041	-.028	-.541	-.493	-.093	-.355
MUS B	-.215	.062	.061	-.422	-.368	-.019	-.272
MUS C	-.241	-.051	-.017	-.514	-.478	-.086	-.350
MUS TOT	-.256	-.011	-.006	-.521	-.473	-.070	-.345

[a]The ultrasound measurements were computed as an average of 3 measurements per site. An $r = .254$ is significant at $p < .01$

TABLE 45. Computation of k constants based on age and gender, and comparison to data from the Phase I experiment and the original Behnke data

Group	N	Age	Height, cm	Weight, kg	3F	% Fat, Density	Sum Fat Widths, cm	k
Young Men								
Phase I	25	23.3	178.2	76.25	6.206	12.85	43.251	.05420
Current	53	23.3	176.9	73.00	6.094	11.79	38.135	.05308
Older Men								
Phase I	25	35.7	177.0	77.25	6.267	19.81	58.653	.04723
Current	36	35.0	177.8	75.50	6.182	16.87	51.755	.04963
Young Women								
Phase I	25	21.9	165.3	57.60	5.600	21.94	67.036	.05456
Current	60	22.9	167.0	60.30	5.701	22.87	63.366	.04860
Older Women								
Phase I	25	34.8	165.2	58.93	5.666	25.10	74.214	.05218
Current	40	34.3	165.1	60.50	5.743	24.75	74.334	.05230
Behnke Data	30	32.0	179.1	84.90	6.532	18.70	57.600	.04710

TABLE 46. Computation of k constants based on fitness status and grouped by age and gender

Group	N	Age	Height, cm	Weight, kg	3F	% Fat, Density	Sum Fat Widths, cm	k
Young Men								
High Fit	26	23.0	176.6	70.43	5.991	9.08	3.1656	.05819
Low Fit	27	23.6	177.2	75.33	6.176	14.15	4.5096	.05160
Older Men								
High Fit	16	35.1	176.5	71.59	6.042	13.77	3.9908	.04797
Low Fit	17	35.0	179.1	79.13	6.308	19.70	6.0193	.04844
Young Women								
High Fit	25	21.8	166.7	58.03	5.597	20.13	5.2994	.04704
Low Fit	35	23.7	167.2	61.86	5.770	24.82	6.9590	.04859
Older Women								
High Fit	16	34.1	164.0	55.83	5.535	21.68	6.5662	.05472
Low Fit	24	34.4	165.9	63.61	5.874	26.80	8.1301	.05164

Computation of k Constants Based on Fitness Status and Grouped by Age and Gender. Table 46 displays the basic mean data for 3F, % body fat, and sum of fat widths that were used to compute the k constants listed in the last column of the table for the high fit and low fit groups of young and older men and women. The k values were computed by the same equation as the derivation of the k constants listed in Table 45 (k = sum fat widths,cm/3F x % body fat).

Summary of k Constants Based on Age, Gender, and Fitness Status. Table 47 is a summary table of k constants based on the Phase 1 and current Phase 2 data. The k constants for gender were constructed from the combined Phase 1 and Phase 2 data (total N = 289 subjects). The k constants based on fitness status are the same as those listed in Table 46.

Comparison Ranking of the Percentage Differences in the k Constants Between the Young and Older Men and Women. Table 48 lists the mean absolute and percentage differences between the k constants for six pairings of the four subgroups. The groups are ranked from the lowest percentage difference between the k constants (2.2% for young men versus older women), to the largest difference between the k constants (9.0% for young men versus older men).

Effect of Using the Gender k Constants to Compute Percent Body Fat Based on Radiography Versus Percent Body Fat Based on Densitometry for the High and Low Fit Men and Women. Table 49 compares percent body fat determined from radiography using the gender k constants from Table 47 for the high and low fit men and women in relation to percent body fat based on densitometry. The range of differences were relatively low between the criterion body fat (densitometry) and body fat computed using the different gender k constants. For example, the largest discrepancy in mean percent body fat occurred for the high fit older women. Using the k constant for older males, percent fat by radiography overpredicted mean percent fat from densitometry by 2.70 percent fat units. On the average, the combined differences between percent body fat determined by radiography and densitometry for the high and low fitness groups for each gender was only 0.70 (young men), 0.77 (older men), 1.4 (young women), and 1.2 (older women) percent fat units. The lowest mean difference between body fat based on radiography and densitometry occurred

TABLE 47. Summary table of k constants based on age, gender, and fitness status

Group	N	k constant[a]
Young Men	78	.05344
High Fit	26	.05819
Low Fit	27	.05160
Older Men	61	.04865
High Fit	16	.04797
Low Fit	17	.04844
Young Women	85	.05035
High Fit	25	.04704
Low Fit	35	.04859
Older Women	65	.05225
High Fit	16	.05472
Low Fit	24	.05164

[a]The k constant for the young and older men and women were computed as an average of the Phase I and current data

TABLE 48. Comparison ranking of the percentage differences in the k constants between the young and older men and women

Group	Δk[a]	% difference between groups[b]
Young Men versus Older Women	.00119	2.2
Older Men versus Young Women	.00170	3.5
Young Women versus Older Women	.00190	3.8
Young Men versus Young Women	.00309	5.8
Older Men versus Older Women	.00360	7.4
Young Men versus Older Men	.00479	9.0

[a]Calculated as the difference between the mean k value for the group in Table 47

[b]Computed in relation to the first group (e.g., young men vs older women is .00119/.05344 x 100 = 2.2%

TABLE 49. Effect of using different gender k constants to estimate body fat from radiography versus body fat measured by densitometry in high and low fit men and women

Group		Percent Body Fat				
	N	Fat_{Db}[a]	$Fat_{k\text{-}YM}$[b]	$Fat_{k\text{-}OM}$[c]	$Fat_{k\text{-}YW}$[d]	$Fat_{k\text{-}OW}$[e]
Young Men						
High Fit	26	9.08	9.89	10.86	10.49	10.11
Low Fit	27	14.15	13.66	15.01	14.50	13.97
Older Men						
High Fit	16	13.77	12.36	13.58	13.12	12.64
Low Fit	17	19.70	17.86	19.61	18.95	19.61
Young Women						
High Fit	25	20.13	17.72	19.46	18.80	18.12
Low Fit	35	24.82	22.57	24.79	23.95	23.08
Older Women						
High Fit	16	21.68	22.20	24.38	23.56	22.70
Low Fit	24	26.80	25.90	28.45	27.49	26.49

[a]Siri equation

[b]k young men (N=78)

[c]k older men (N=61)

[d]k young women (N=85)

[e]k older women (N=65). The k values are summarized in Table 47, and body fat was computed using the 3F and sum of fat widths shown in Table 46 for the high and low fitness groups. For example, body fat for the high fit young men using the k value for young men in Table 47, and the 3F and sum of fat widths from Table 46, is % fat = 3.1656/5.991 x .05344 (k young men) = 9.89

for the low fit young women; the mean difference was only 0.03 percent fat units (using the k constant for young men).

DISCUSSION

The results of the Phase 2 research are straightforward and extend the basic findings reported in Phase 1. The salient finding is that the arm x-ray technique is a valid procedure in young and older men and women who differ in fitness status determined by maximal oxygen consumption. Based on the results from Phase 1, it was determined that the k constants were age specific for young and older men and women. This same finding was also found for the larger sample of men and women in the current Phase 2 research. In addition, the results showed that the k constants were fitness specific.

From a practical standpoint, if an individual's fitness status is known, then the appropriate k constant listed in Table 47 based on age and fitness can be used with the basic equation (% fat = fat thickness/3F x k) to compute percent body fat from the x-ray widths. In this study, fitness was operationally defined as the maximal oxygen consumption (max$\dot{V}O_2$, ml/kg·min^{-1}) measured during treadmill test procedures. If other means for evaluating the max$\dot{V}O_2$ correlated highly with the treadmill measured max$\dot{V}O_2$, then such tests (bicycle ergometer, step bench, swim flume, rower, stair climbing, walk-run performance test) could be used to classify individuals into high and low fitness categories. For different populations, however, it may be necessary to adjust slightly the cut-off points we established a priori to define a "low" max$\dot{V}O_2$ for young men (< 60 ml/kg^{-1}), older men (< 50 ml/kg^{-1}), young women (< 47.9 ml/kg^{-1}), and older women (< 42.9 ml/kg^{-1}). For subjects in the "high" fitness category, their max$\dot{V}O_2$ scores were larger than defined for the subjects in the low fitness category.

Table 50 compares the percent body fat from densitometry and the average percent body fat based on the x-ray data using the pooled age-specific k constants for young and older men and women. On a percentage basis, the comparisons are relatively close, especially for the unfit groups. For example, there was only a 1.0 percent difference between the two methods of determining fatness

TABLE 50. Comparison of percent body fat based on densitometry and the average percent fat from the combined data using the k constant for the young and older men and women

	Percent fat, density	Percent fat, combined[a]	% diff[b]
Young Men			
High Fit	9.08	10.34	13.9
Low Fit	14.15	14.29	1.0
Older Men			
High Fit	13.77	12.93	6.1
Low Fit	19.70	19.01	3.5
Young Women			
High Fit	20.13	18.53	7.9
Low Fit	24.82	23.60	4.9
Older Women			
High Fit	21.68	23.21	7.1
Low Fit	26.80	27.08	1.0

[a]Calculated as an average of the 4 methods of computing percent body fat based on the k constants for the young and older men and women. These values are from the last 4 columns in Table 49.

[b]Calculated as percent fat, density minus percent fat, combined/ percent fat, density x 100

for the low fit young men and low fit older women. The differences were only 3.5 percent for the low fit older men and 4.9 percent for the low fit young women. This contrasts with the 13.9 percentage difference for the high fit young men, and 7.9 percentage difference for the high fit young women. The corresponding values were 7.1 percent (high fit older women) and 6.1 percent (high fit older men). We are unable to explain why the comparisons were slightly more favorable for the low fit groups. In total, the comparisons expressed on a percentage basis provide a further basis for recommending that the conversion to percent body fat be based on the age and fitness specific k constants listed in Table 47.

There are two major areas of research that need to be addressed in further studies on this topic. First, it needs to be determined whether the k constants are appropriate for use with males and females who reduce their body weight and percentage body fat. It seems to us that an appropriate paradigm for inducing weight loss would be a combination of exercise and mild dietary restriction. A reasonable weight loss would be approximately 10-15 pounds; if possible, it would be of interest to know if the k constants were valid for greater amounts of weight loss. One of the unanswered questions is whether the decrements in body weight and body fat result in corresponding and proportional decreases in the width of fat measured on the x-ray.

A second important area of research is to determine the validity of the arm x-ray procedure for non-Caucasian populations such as in Blacks and Hispanics. If it turned out that validity was high as for the Caucasian subgroups (Phase 1 and current report), then the arm x-ray procedure would have universal application to a variety of racial groups. This would permit widespread use in a variety of military and non-military applications.

CONCLUSIONS

The results of the Phase 2 research can be summarized as follows:

1. The young and older age groups of men and women were successfully placed into high and low categories of relative fitness status assessed by treadmill max$\dot{V}O_2$. The physical and dimensional characteristics of the subjects were compared by assessment of fatfolds, girths, bone diameters,

ultrasound subcutaneous fat, and fat, muscle, and bone widths from an upper arm x-ray. Physiological data from the max$\dot{V}O_2$ tests (relative and absolute) included comparisons of max $\dot{V}CO_2$, max R, max $\dot{V}_E$, and HR at max$\dot{V}O_2$.

2. For the total sample of subjects (N = 176), including the subgroups of young males (N = 53), older males (N = 33), young females (N = 60), and older females (N = 40), the intercorrelations were moderately high between percent body fat (densitometry) and the width of fat measured at three sites on the x-ray (r = .643 to r = .832. The highest correlations were obtained between body fat (densitometry) and the sum of the 3 fat widths; r = .884 for the total sample; r = .795 for young males; r = .864 for older males, r = .825 for young females, and r = .828 for older females. The correlations were low and negative between the various bone and muscle widths and body fat (densitometry) for the age and gender subgroups.

3. The correlations were moderately high between seven fatfolds and the three fat widths on the x-ray for the young and older males and females. The exceptions were for the iliac, abdomen, and subscapular fatfolds, and sum of x-ray widths (r = .463 for the iliac, r = .587 for the abdomen, and r = .630 for the subscapular. The correlations for the other sites ranged from r = .795 for the biceps fatfold to r = .873 for the triceps fatfold. The corresponding correlations were higher in the younger males and females compared to their older counterparts.

4. When various combinations of fatfolds were correlated with the fat x-ray widths, the magnitude of the relationship was larger compared to the use of the single fatfolds. The increase in the correlations did not improve substantially when more than three fatfolds were summed (biceps, triceps, scapula). For the total sample, r = .873 between the sum of three fatfolds and the sum of the fat x-ray widths; it was only r = .883 when seven fatfolds were used.

5. When ultrasound subcutaneous fat was correlated to the fat x-ray widths, the same pattern of results emerged as for the fatfolds. For the total sample, r = .786 when the same three

ultrasound sites were used; adding four more sites improved the correlations to r = .841. The pattern of the correlations was similar for the young and older males and females. The correlations were generally low and all were negative between the seven ultrasound sites and the individual and sum of muscle x-ray widths.

6. An equation was used to convert basic anthropometric data into age and gender specific k constants. The k constant was calculated from the equation, k = sum fat x-ray widths/3F x % body fat, where 3F = 3 x $\sqrt{}$Wt,kg/Ht,dm, and the values for sum fat x-ray widths, 3F, and % body fat were the group mean values.

7. New k constants were also computed for the male and female subgroups who were classified into high and low fitness categories. On the average, the combined differences between percent body fat determined by radiography and densitometry for the high and low fitness groups for each gender were 0.70 (young men), 0.77 (older men), 1.4 (young women), and 1.2 (older women) percent fat units. The lowest mean difference occurred for the low fit young women; the mean difference was only 0.03 percent fat units (using the k constant for young men).

8. The overall results illustrate that the arm x-ray technique is a valid procedure to estimate the body fat content in young and older men and women who differ in fitness status determined by maximal oxygen consumption. The k constants appear to be age, gender, and fitness specific. The effect of interchanging the k constants among the age and gender groups resulted in mean differences for percent body fat that ranged from 2.2% (young men versus older women) to 9.0% (young men versus older men). The percentage differences were of the same order of magnitude when the fitness-specific k constants were applied to the different age and gender subgroups.

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Appendix I

INFORMED CONSENT DOCUMENT
BODY COMPOSITION PROJECT/RENEWAL

ANTHROPOMETRIC-ARM RADIOGRAMMETRIC ASSESSMENT OF BODY FATNESS, MUSCULARITY AND SKELETAL FRAME SIZE

Your written consent is required before you can participate in the Body Composition Project. Please read this document carefully and then sign your name in the space provided. The following guidelines are established in accord with the Code of Federal Regulations 45, Public Welfare, Part 46, Protection of Human Subjects, and with legal requirements applicable to the University of Massachusetts. These guidelines supercede those contained in Senate Document 72-061 and became effective on September 1, 1978. In accord with the Code of Federal Regulations as described immediately above, and as amended November 3, 1978 by Federal Register Document 78-30752 Interim Final Regulation, and in accord with the directive of the Office of Protection from Research Risks of the NIH following policy amendments by the University of Massachusetts/Amherst General Assurance G0147XM, the following policy amendments by the University Human Subjects Review Committee were adopted on February 15, 1979.

PURPOSE: To develop a simple, reliable and valid method of body composition evaluation.

PROCEDURES:

1. Your height and weight will be measured.

2. Twelve circumference measurements will be taken with a cloth tape. The sites include: neck, shoulders, chest, hips, abdomen, thighs, knees, calves, ankles, wrists, forearms, biceps.

3. Eight bone measurements will be taken with a wooden caliper. The sites include: shoulders, chest, hips, ankles, knees, wrists, elbows.

4. Five surface fat measurements will be taken with a skinfold caliper. The sites include: back of arm, shoulder blades, hip, abdomen, mid-thigh.

5. Ultrasound measurements for fat determination will be taken at seven sites: back of the arm, biceps, shoulder blades, hip, abdomen, mid-thigh, and calf.

6. Your body volume will be measured by a water immersion test. You will be seated in a chair suspended in a water tank. You will exhale your air and submerge. You will hold your breath for 3 seconds while submerged in a bent-forward position. This procedure will be repeated 10 times with ample time between. The chair is balanced so your sitting position is maintained throughout the test.

7. You may use a snorkel if you wish. A nose clip and ear plugs can also be worn. You may raise your face out of the water at any time. The procedure is similar to sitting in a bath tub with the water level up to your neck. You then lean forward to submerge your head while you are weighed submerged.

8. We will also measure the volume of your lungs. This is done before the water test. You will sit in a chair and breathe into the lung machine (spirometer) for 6 to 8 normal breaths. A nose clip is worn. The procedure takes about 15 seconds, and is repeated twice. The lung score is needed in the calculation of body composition.

9. An x-ray will be taken of your right upper arm (between your elbow and shoulder). This will be done in the x-ray department of the University Health Services by a licensed x-ray technician. The x-ray dosage is 10 mR (milliroentgens), which is the same dosage as a standard x-ray. As a frame of comparison, the x-ray mR exposure is 200 for a back x-ray, 23 mR for a foot x-ray, and 150 mR for an abdominal x-ray. The average x-ray exposure from non-occupational sources (environment) is 100 mR per year at sea level.

DISCOMFORT OR RISKS:

1. There are no discomforts or risks with the various body composition tests. In very rare cases, subjects may swallow a small amount of water if they inhale instead of exhale during water submersion.

2. There may be some as yet unknown long term effects of exposure to x-ray; there is no scientific evidence that a 10 mR exposure equivalent to a standard chest x-ray poses any short-term or long-term harmful effects to humans.

BENEFITS:

1. Participation in a scientific research study.

2. Contribution to the advancement of science in the field of human body composition research with immediate practical application to the allied medical professions.

3. Remuneration of 15 dollars for completion of all testing.

4. Knowledge of your results about the various tests.

ALTERNATIVE PROCEDURES:

1. The current techniques are commonly in use throughout the world, both in children and adults of both sexes.

2. Alternative procedures were not considered as they are complex and invasive (isotopic dilution) and impractical (potassium counting and neutron activation).

QUESTIONS AND ANSWERS:

1. All questions concerning any of the procedures will be answered before or after testing.

WITHDRAWAL:

1. You are free to withdraw consent and discontinue participation at any time during testing, without penalty or loss of benefits to which you are otherwise entitled.

CONFIDENTIALITY:

1. All data obtained will be kept confidential. You will not be identified by name or any other means in any summaries, publications, or reports that result from the research.

In addition to the items discussed in this document, the principal investigator (Dr. Frank Katch) will conduct all procedures with consideration of your best interests and to insure your safety and comfort. Dr. Katch serves as the contact person for all information pertaining to the project.

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